National Aeronautics and
Space Administration

A Home in Space:
Future Habitat Development Efforts at NASA

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NASA Marshall Space Flight Center

Habitation Systems Development Office

ARTEMIS

In-space Manufacturing
Project

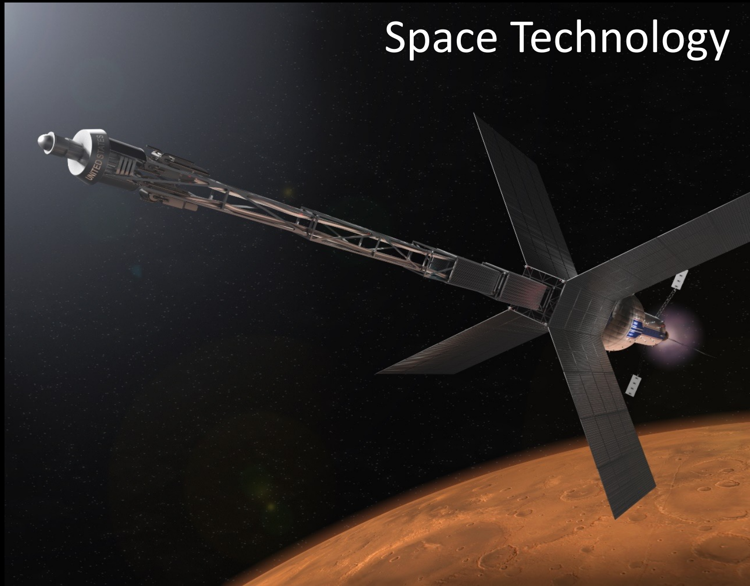
Nametag from door of
my childhood bedroom

NASA Marshall Space Flight
Center (2013-present)

B.S. Physics
M.S., Ph.D. Mechanical Engineering

Young Astronauts Club

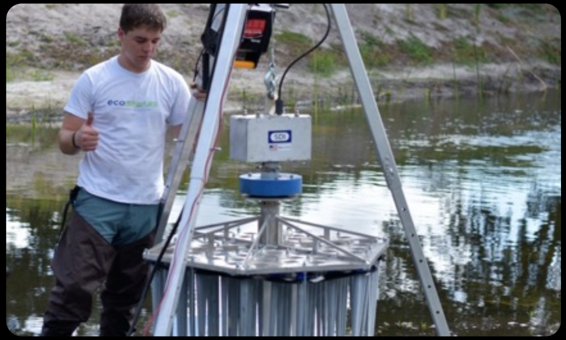
What does NASA do?



Everyone benefits from exploration:

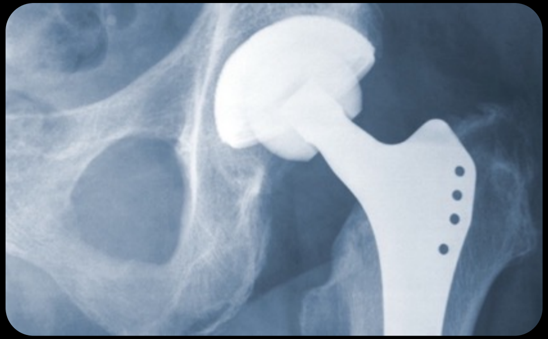
Students

Construction Workers



Conservationists

Farmers



Doctors and Patients

Airplane Passengers

First Responders

What is a space habitat?

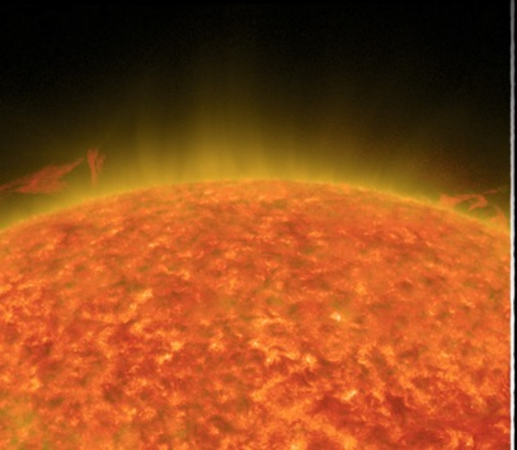
A space habitat is a home in space, designed to support crew on longer duration missions.

Skylab was the first US orbiting space station and operated with crew from 1973 to 1974.

Hazards of Human Spaceflight

1 Space Radiation

Invisible to the human eye, radiation increases cancer risk, damages the central nervous system, and can alter cognitive function, reduce motor function and prompt behavioral changes.



2 Isolation and Confinement

Sleep loss, circadian desynchronization, and work overload may lead to performance reductions, adverse health outcomes, and compromised mission objectives.

3 Distance from Earth

Planning and self-sufficiency are essential keys to a successful mission. Communication delays, the possibility of equipment failures and medical emergencies are some situations the astronauts must be capable of confronting.

4 Gravity (or lack thereof)

Astronauts encounter a variance of gravity during missions. On Mars, astronauts would need to live and work in three-eighths of Earth's gravitational pull for up to two years.

5 Hostile/Closed Environments

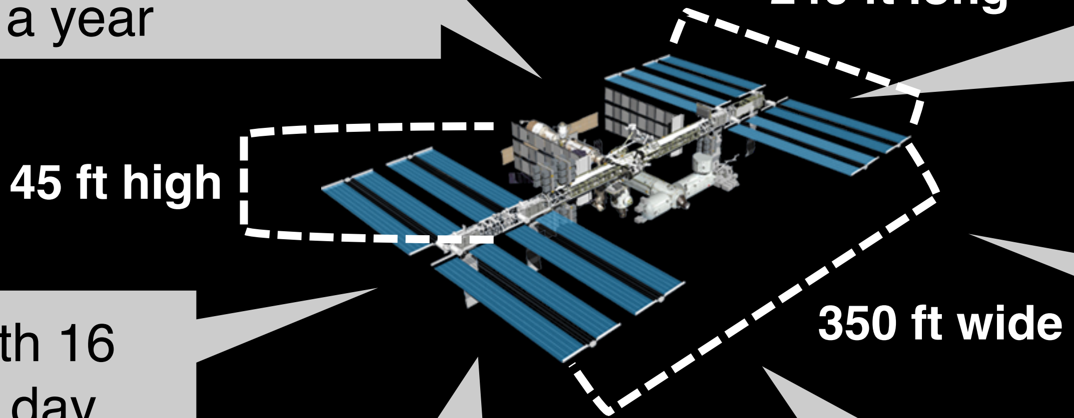
The ecosystem inside a vehicle plays a big role in everyday astronaut life. Important habitability factors include temperature, pressure, lighting, noise, and quantity of space. It's essential that astronauts stay healthy and happy in such an environment.

The International Space Station: Facts & Figures

The space station was built in orbit over 41 assembly flights between 1998 and 2011.
There have been 215+ successful launches to ISS to date to deliver crews, supplies, and science.

Continuously crewed for 21 years since 2000; crew stays now range from six months to a year

2,800 publications have been produced from ISS research; 200 experiments are operating at any given time



Orbits Earth 16 times per day

Travels approximately 250 miles above the Earth at 17,500 mph

Orbital path covers 90% of Earth's population

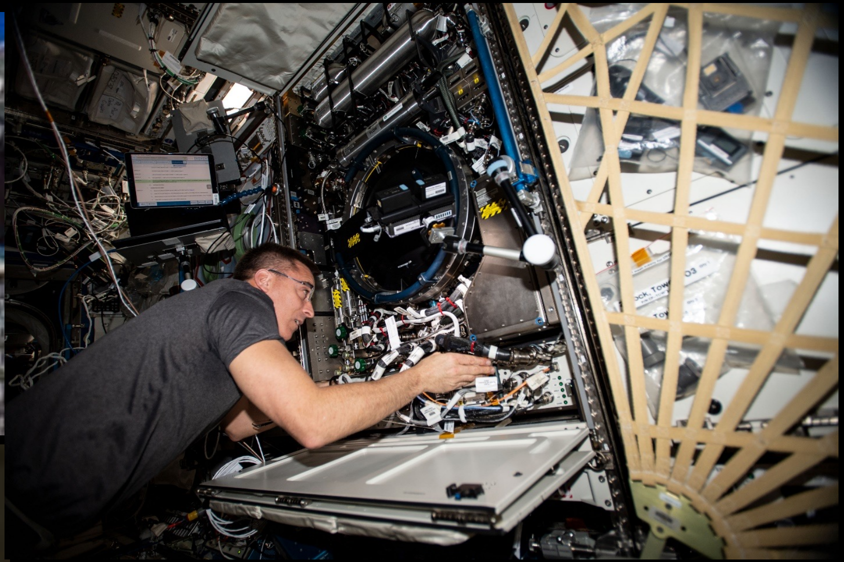
Internal volume of 32,333 cubic feet about the size of a 6-bedroom house

nasa.gov/station

What does a space habitat do?

More Functions of a Space Habitat

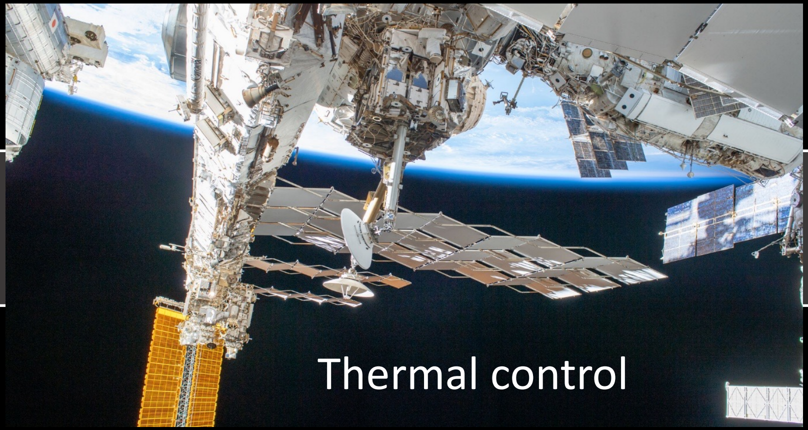

Stowage

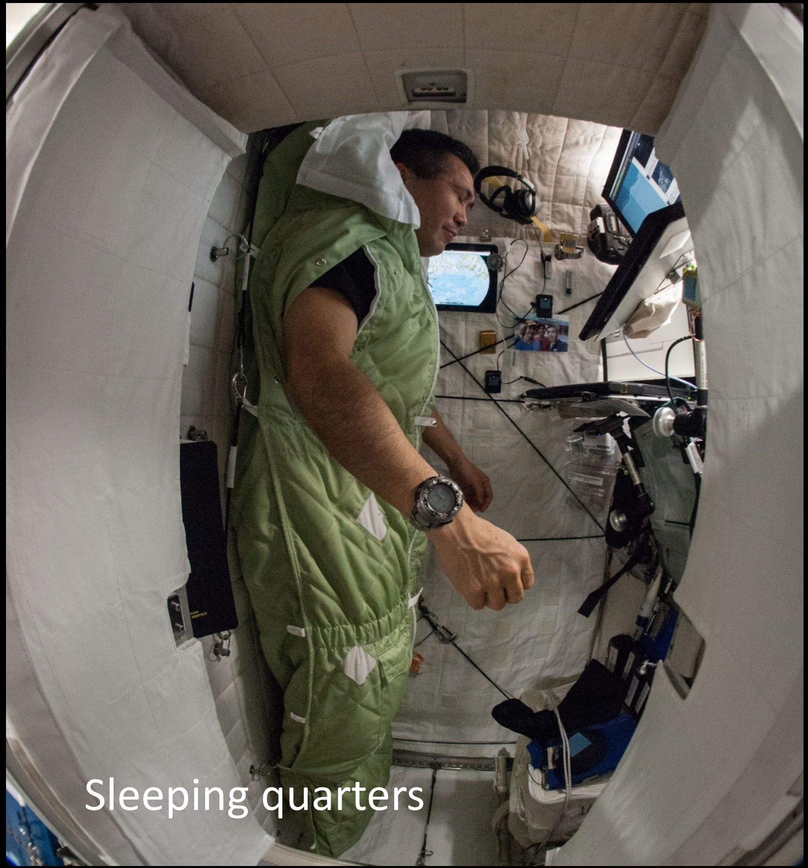

Maintenance and Repair


Extravehicular activity


Food storage and
meal preparation


Trash disposal


Thermal control



Even More Functions of a Space Habitat

Human Needs on Space Missions

	Amount per crew member per day	4 crew on 30-day lunar surface mission
Food	2.4 kg (5.3 lbs)*	288 kg (635 lbs)
Drinking Water**	2.8 kg (6.2 lbs)	336 kg (744 lbs)
Water for food	0.5 kg (1.1 lbs)	60 kg (132 lbs)
Oxygen**	0.9 kg (2.0 lbs)	108 kg (240 lbs)
Clothing	0.2 kg (0.4 lbs)	24 kg (48 lbs)
Trash produced	1.7 kg (3.7 lbs)	204 kg (440 lbs)
CO_2 produced**	1.1 kg (2.4 lbs)	132 kg (291 lbs)

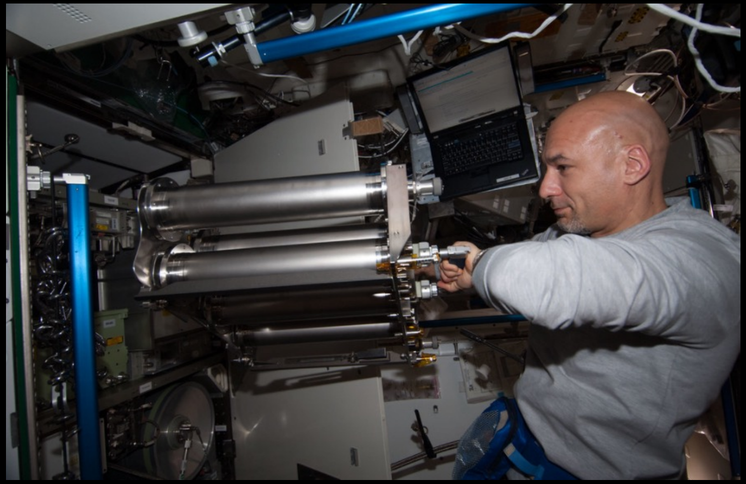
*about 15 percent of this weight is food packaging material ** assumes 82 kg astronaut for consumables planning (~180 lbs)

Life Support Systems Provide Clean Air and Water

Two types of Environmental Control and Life Support Systems (ECLSS):

- Open loop ECLSS = provide all water, oxygen, and food from either stowed materials or cargo resupply
  - No recycling of outputs to inputs
- Closed loop systems process waste products into other resources and recover usable constituents
  - Closed loop ECLSS reduces dependence on resupply and imparts significant mass savings for future missions
  - Earth itself is a closed loop ECLSS system

Urine Processor Assembly



Water Processing Assembly

Oxygen Generation System

Carbon Dioxide Removal Assembly

6,200 Gallons

The amount of potable water recovered from space station crew urine since installation in 2008—equivalent to 46,959 16-ounce bottles of water!

319 Standard Bathtubs

That's how much water has been purified by the ECLSS system's Water Processing Assembly between 2008–2021: more than 13,414 gallons.

13,139 Average Homes

That's how much cubic space the life support system has scoured free of CO_2 in the station since 2008.

4,300 Hours

Marshall is extending the original Urine Processor Assembly's 1,400-hour lifespan by nearly 3,000 hours—adapting proven life support system technologies for long-duration human missions to the Moon and Mars.

ECLSS Around the World

Space station water purification technology developed by NASA and its partners has applications here on Earth—bringing life-saving pure water to remote, arid, or disaster-ravaged regions across the globe, including areas in India, Iraq, Pakistan, and Central and South America.

98%

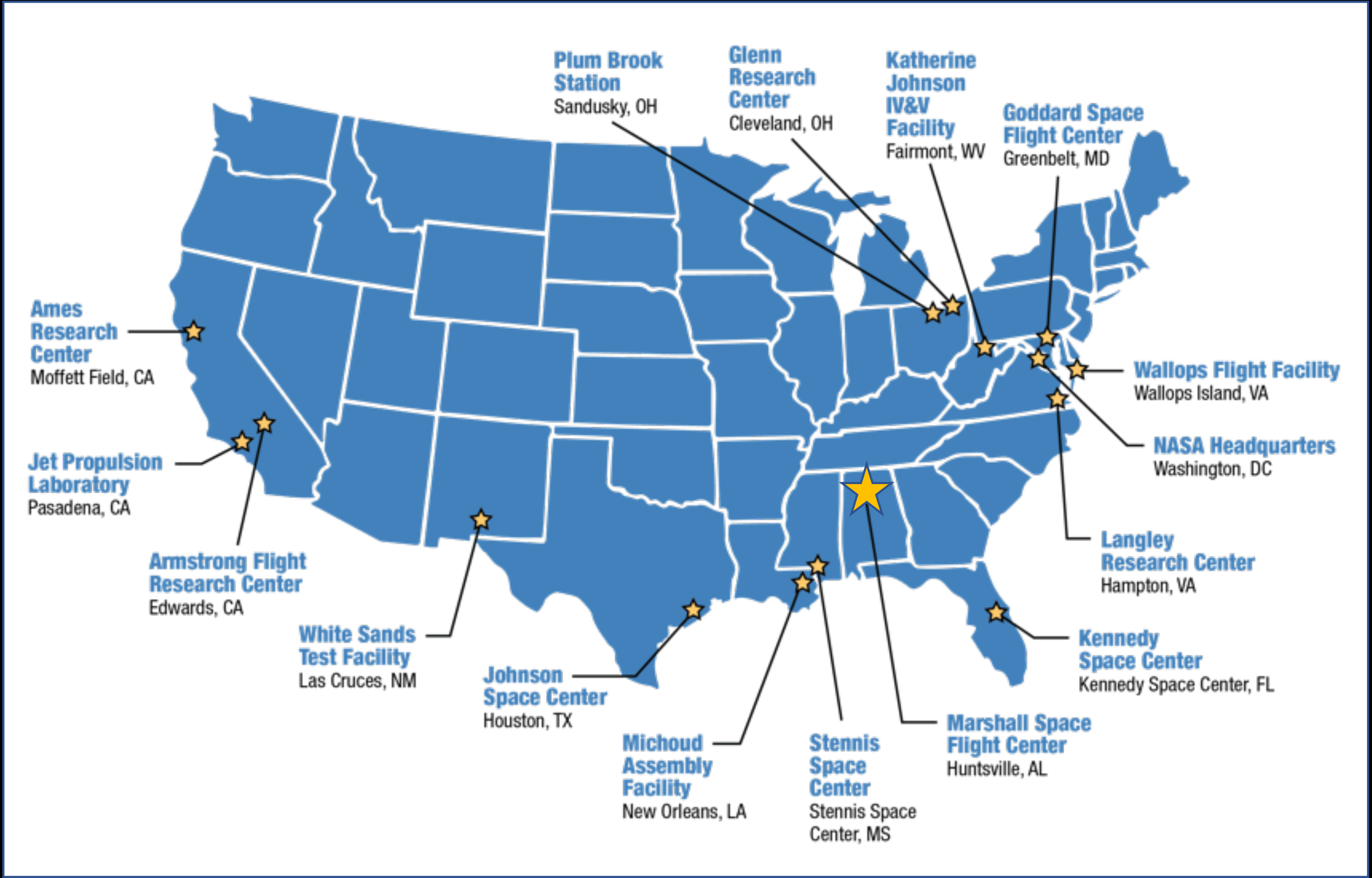
NASA's goal for life support system air/water recovery on long-duration missions beyond Earth orbit. We can achieve 93% now with current water reclamation systems. The best is yet to come!

ARTEMIS

Twin sister of Apollo and goddess of the Moon in Greek mythology, Artemis is the torch-bringer personifying our path to the Moon. During the next era of human exploration, we will discover life-saving, Earth-changing science and technology along the way.

NASA’s goal is to land the first woman and first person of color on the Moon. When the Artemis astronauts land on the lunar surface, they will step into the future, bringing all of humanity with them.

Every NASA Center Contributes to Artemis



Suppliers and small businesses across America have made contributions to the success of NASA's Artemis program.

Private companies are hard at work on innovations that will help establish a sustainable human presence at the Moon. The Artemis endeavor also extends beyond our borders.

For detailed information about NASA's partners and where to find them, visit the Artemis partners map at www.nasa.gov/content/artemis-partners

The International Space Station is a Testbed for Artemis Missions

Orbiting Earth for nearly 20 years, the space station is the only long-term platform available to validate the technologies, operations, and skills we need to travel farther for longer durations

Life Support Systems

Next Generation Spacesuits

Advanced Technology

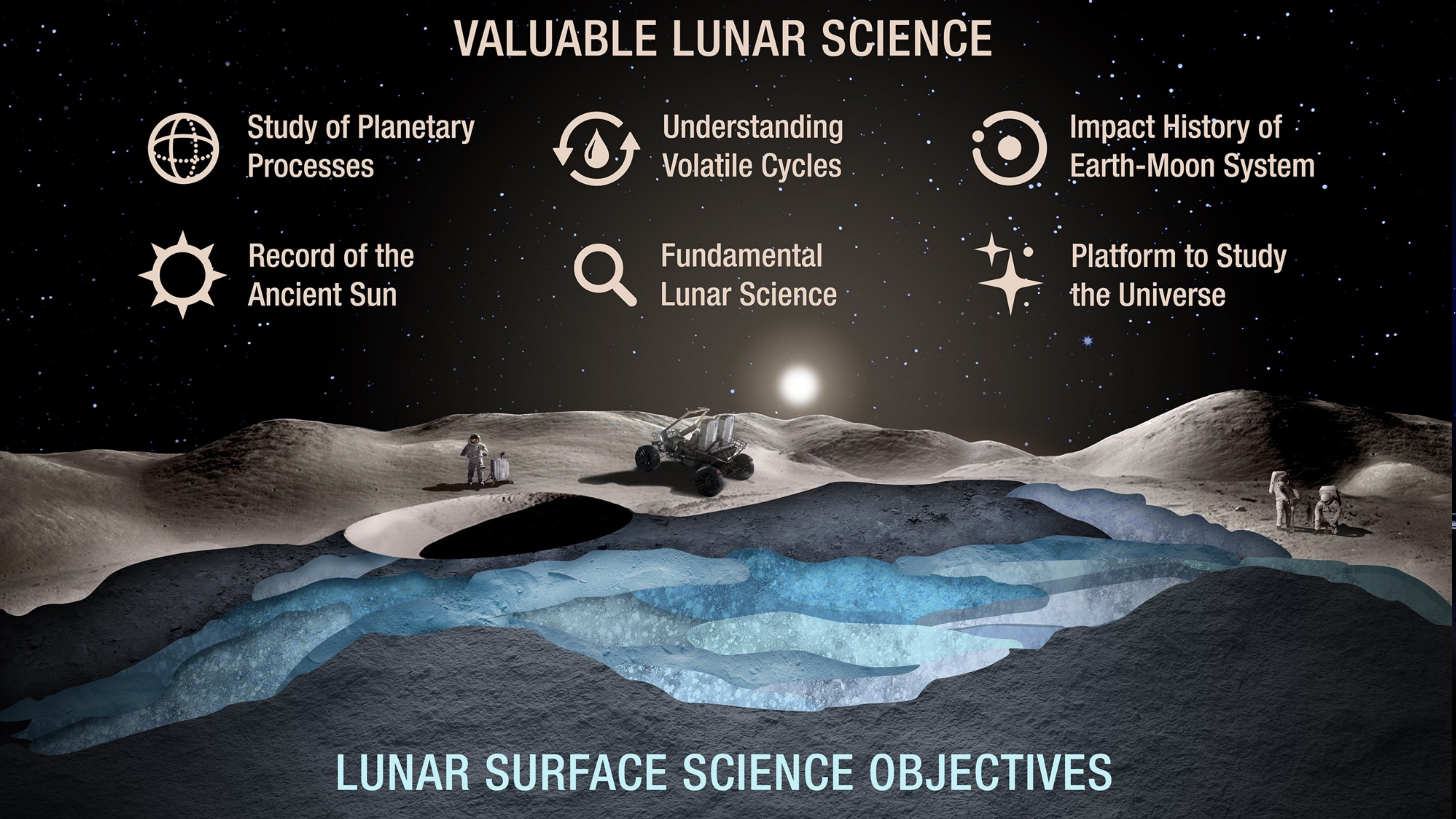
Crew Health and Performance

Human Research

These capabilities are just a few examples of the necessary technology and strategies being tested on the space station

Next Steps: Going Farther, Staying Longer

Longer duration missions farther than low earth orbit will present new challenges that lie beyond previous human spaceflight experience.


VALUABLE LUNAR SCIENCE
Study of Planetary Processes
Understanding Volatile Cycles
Impact History of Earth-Moon System
Record of the Ancient Sun
Fundamental Lunar Science
Platform to Study the Universe
LUNAR SURFACE SCIENCE OBJECTIVES

HLS

Initial Human Landing System

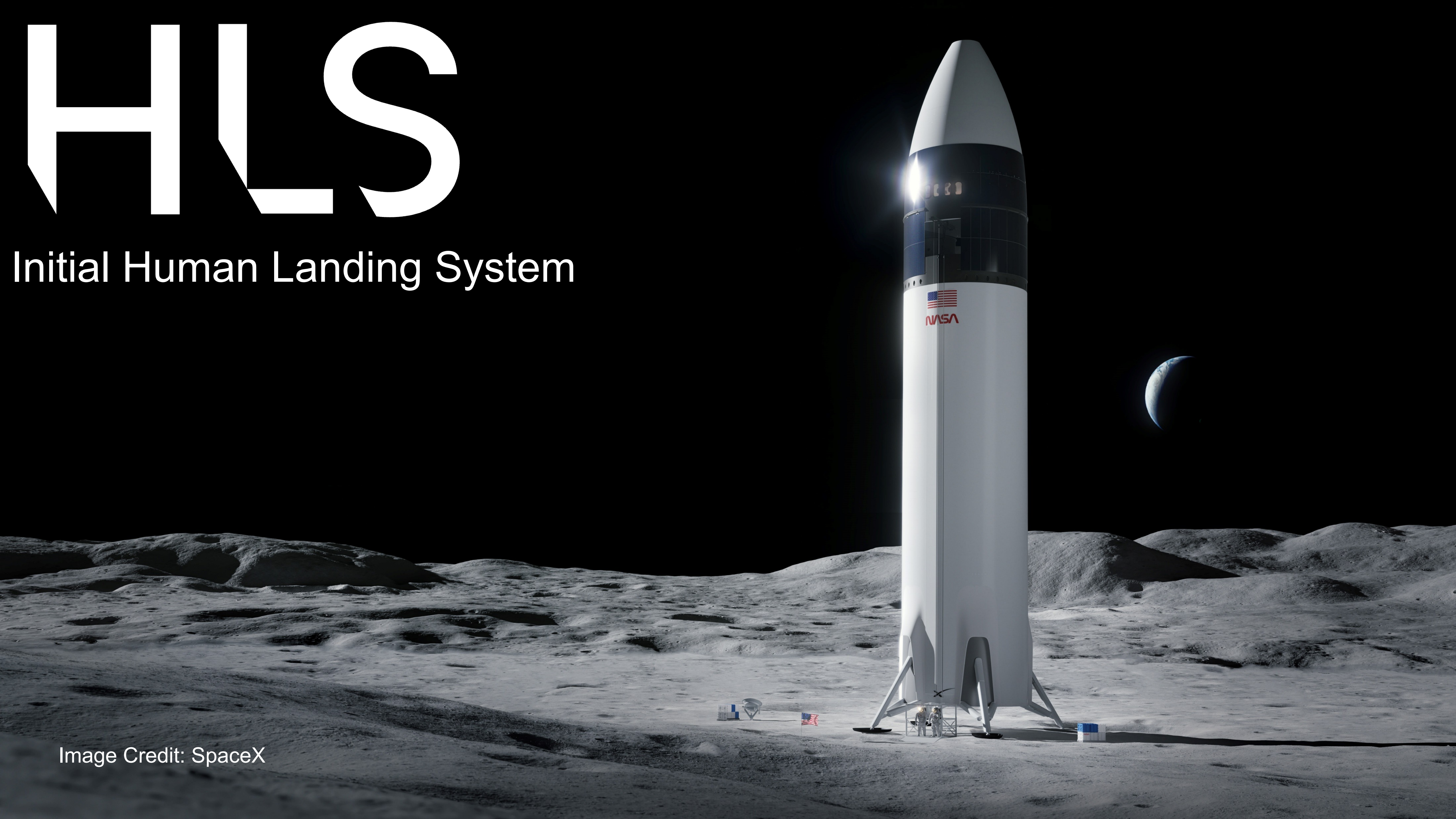
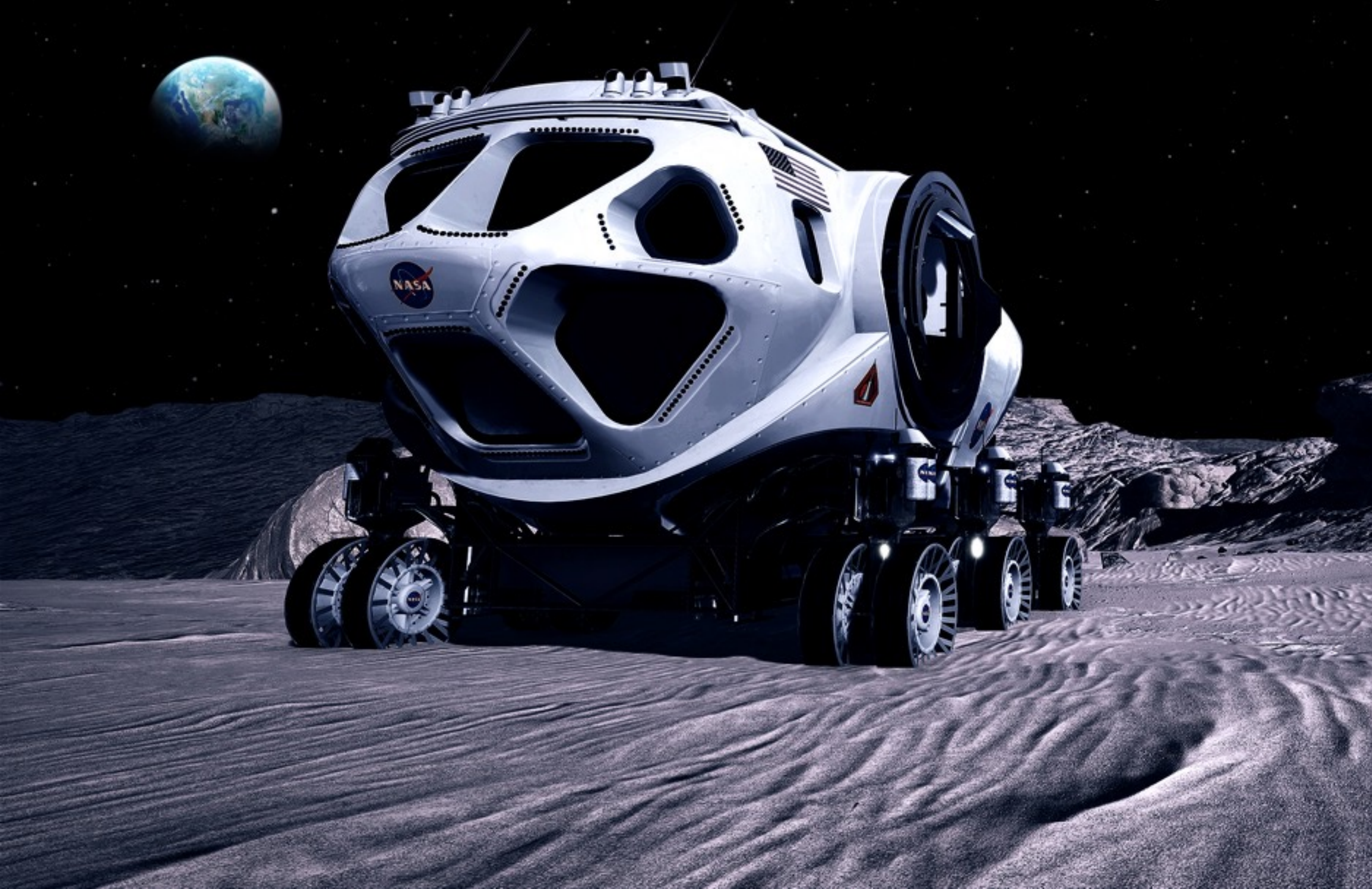


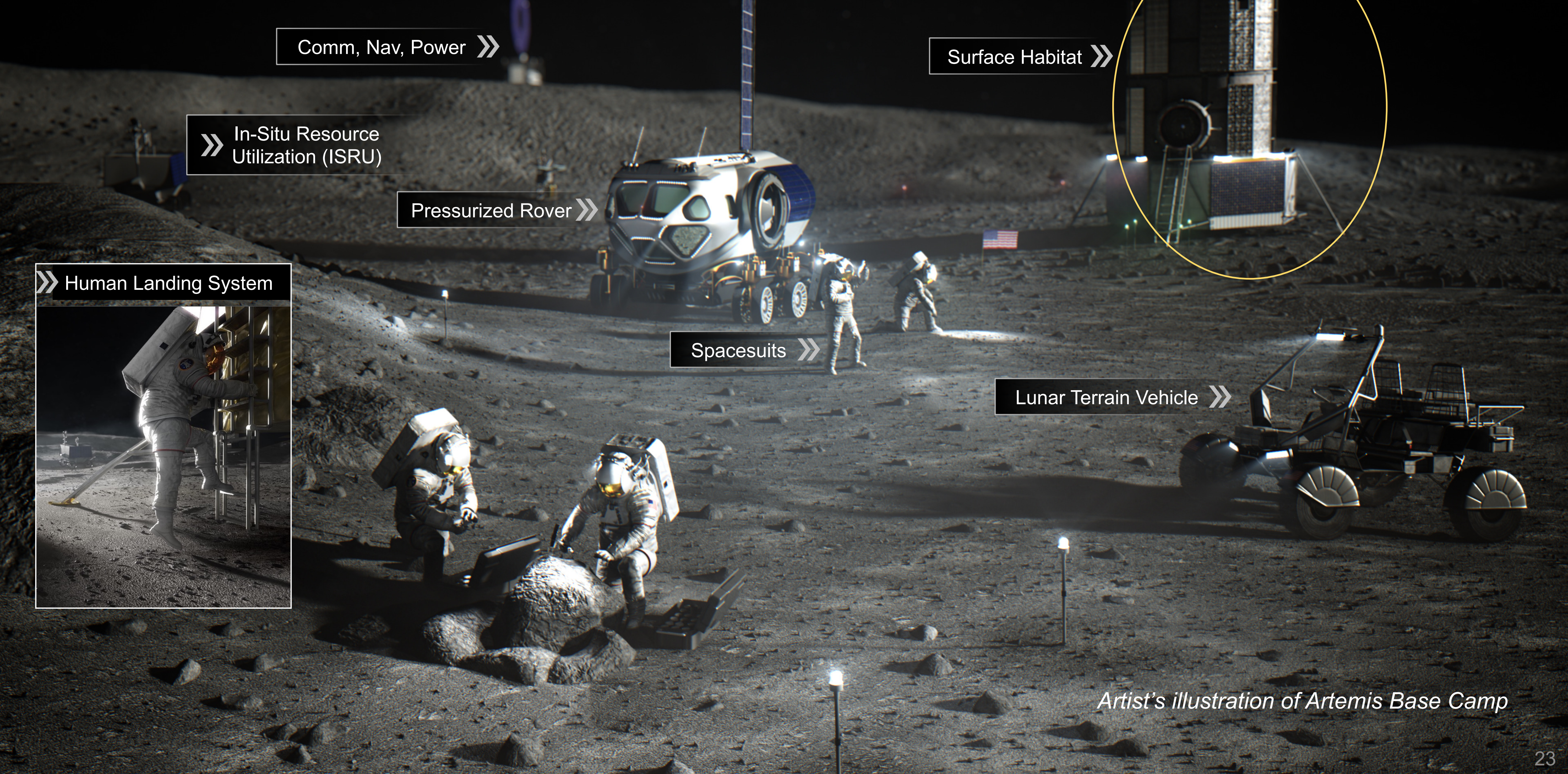
Image Credit: SpaceX


GATEWAY

PRESSURIZED ROVER



ARTEMIS BASE CAMP



Artist's illustration of Artemis Base Camp

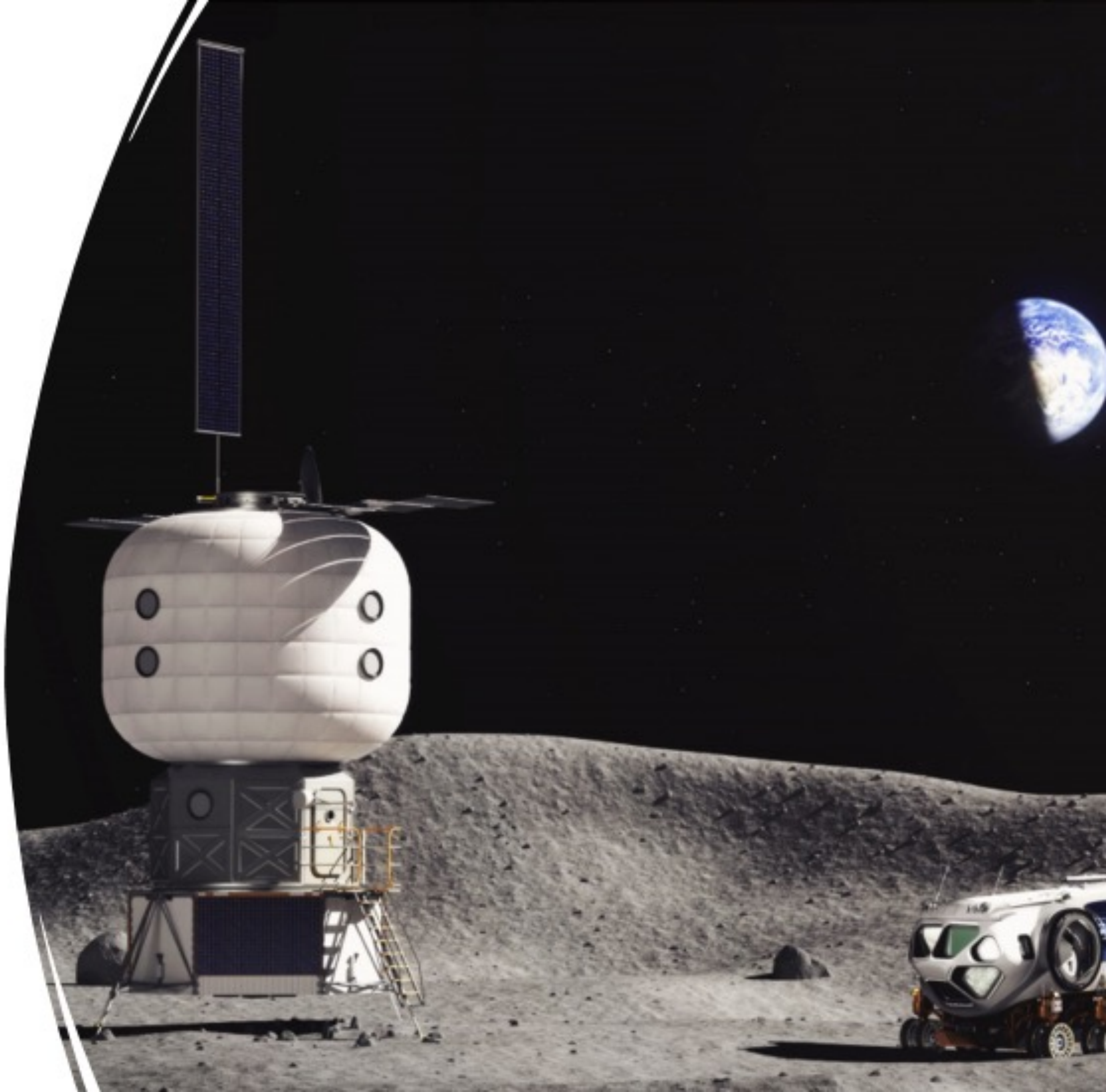
Surface Habitat | Overview

Objective:

- A primary asset to achieve a sustained lunar presence and serve as a platform for Mars mission preparations
- NASA is working with industry to develop conceptual designs for the Surface Habitat

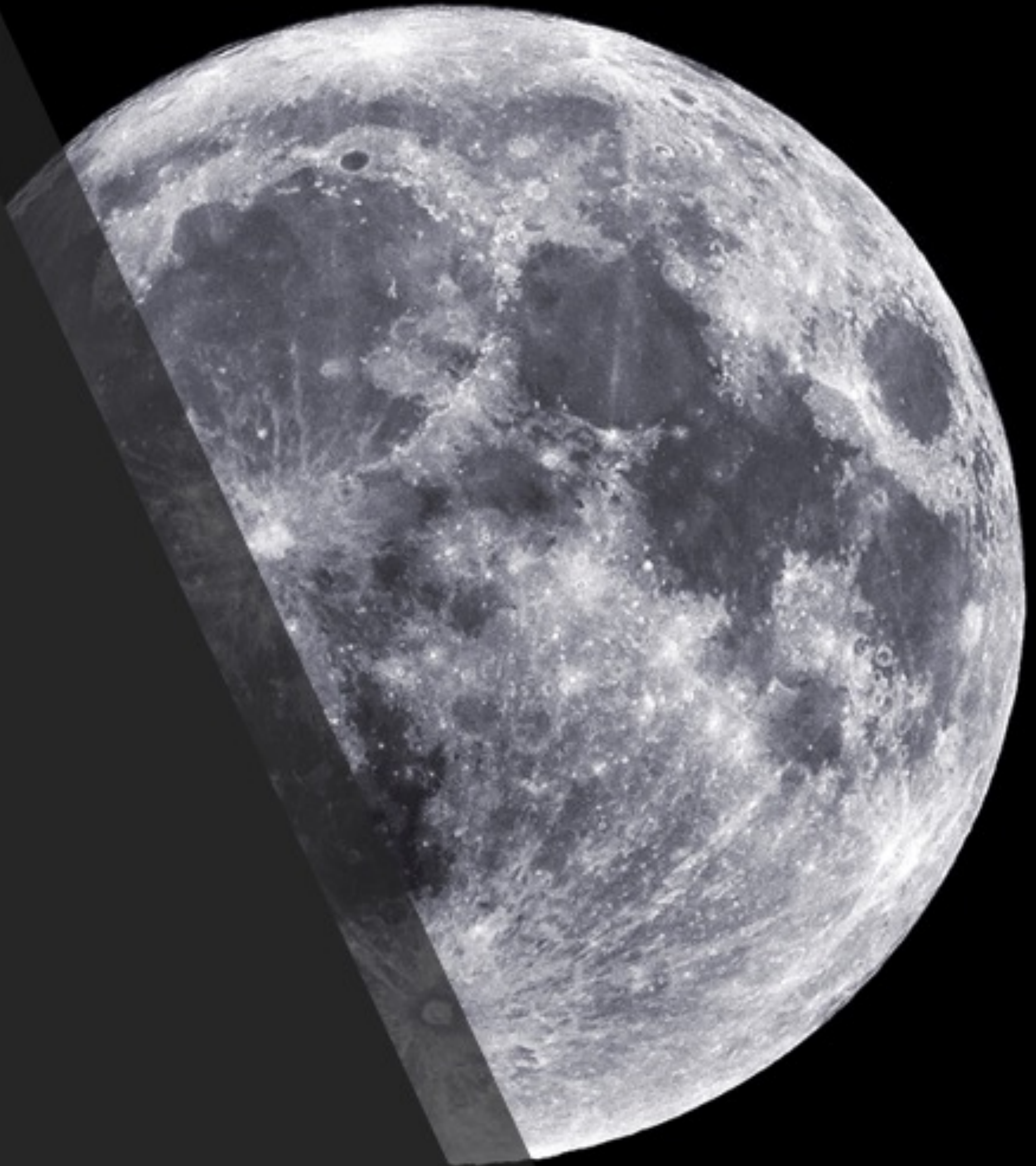
Capabilities:

- 2-4 crew – medical, exercise, galley, crew quarters, stowage
- 30-60 day capable habitat
- EVA capable via air lock with suit maintenance capability
- Power generation, recharge capability for surface assets
- Communication hub for surface assets



Surface Habitat | Challenges

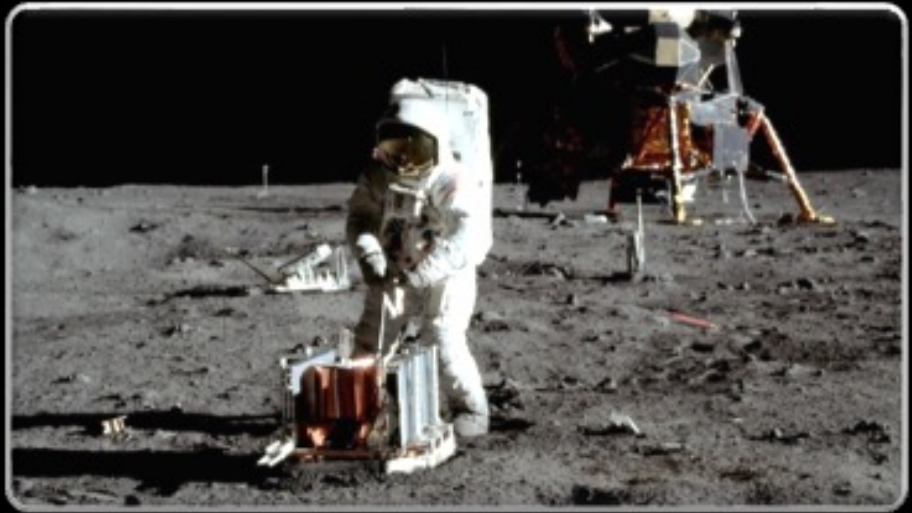
- Delivery Mass
- Functional Volumes
- Outfitting
- Dust contamination
- Dormancy
- Survive the night thermal/power
    - Power conservation
    - Energy storage solutions with improved energy density
- Logistics transfer and loading
- Capability to maintain and repair external systems



Taking the Next Giant Leap

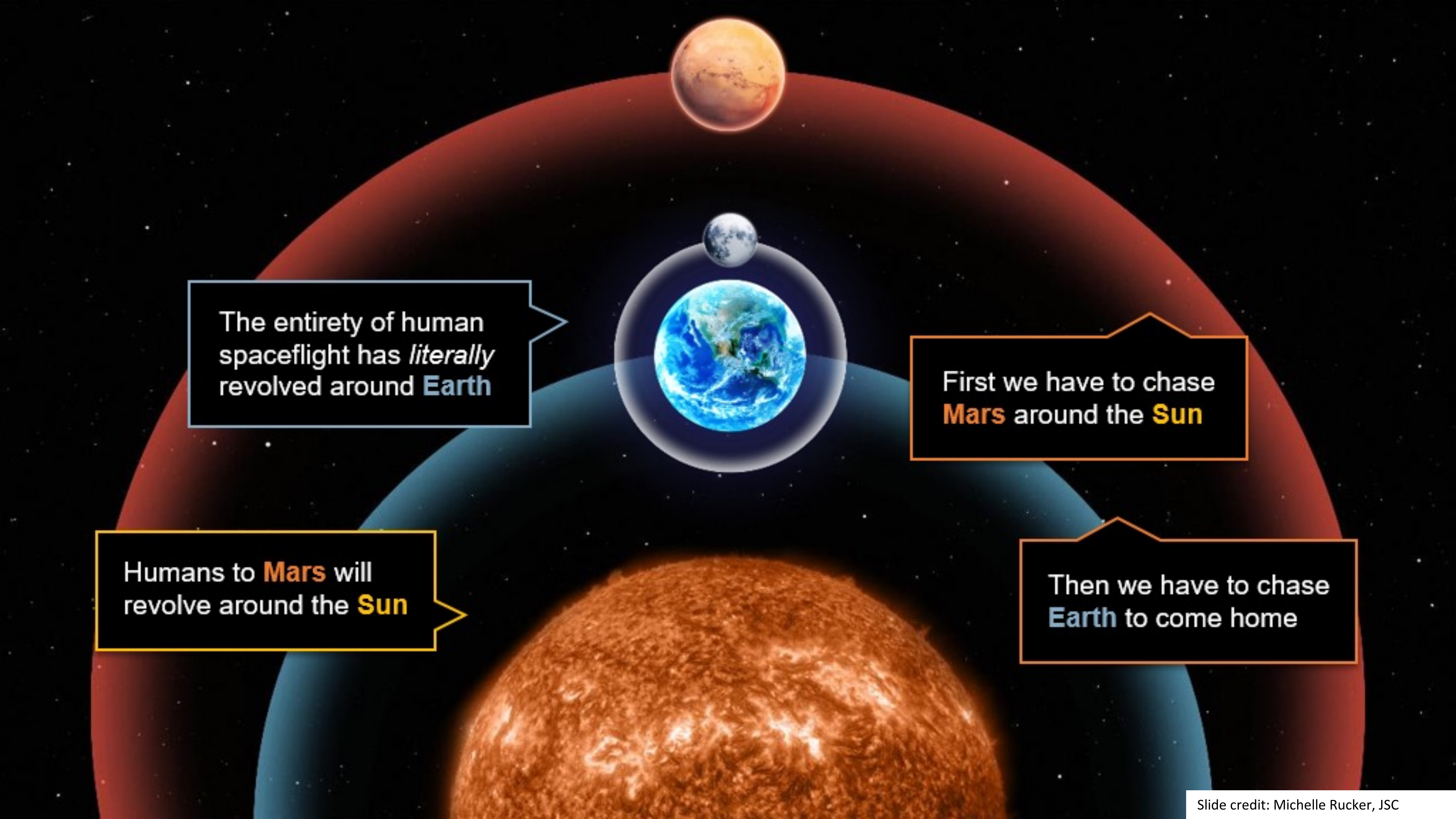
Humans on Mars

Validating Crew Health and Performance *in Artemis Spacecraft* Will Help Prepare Us to Live and Work on Mars



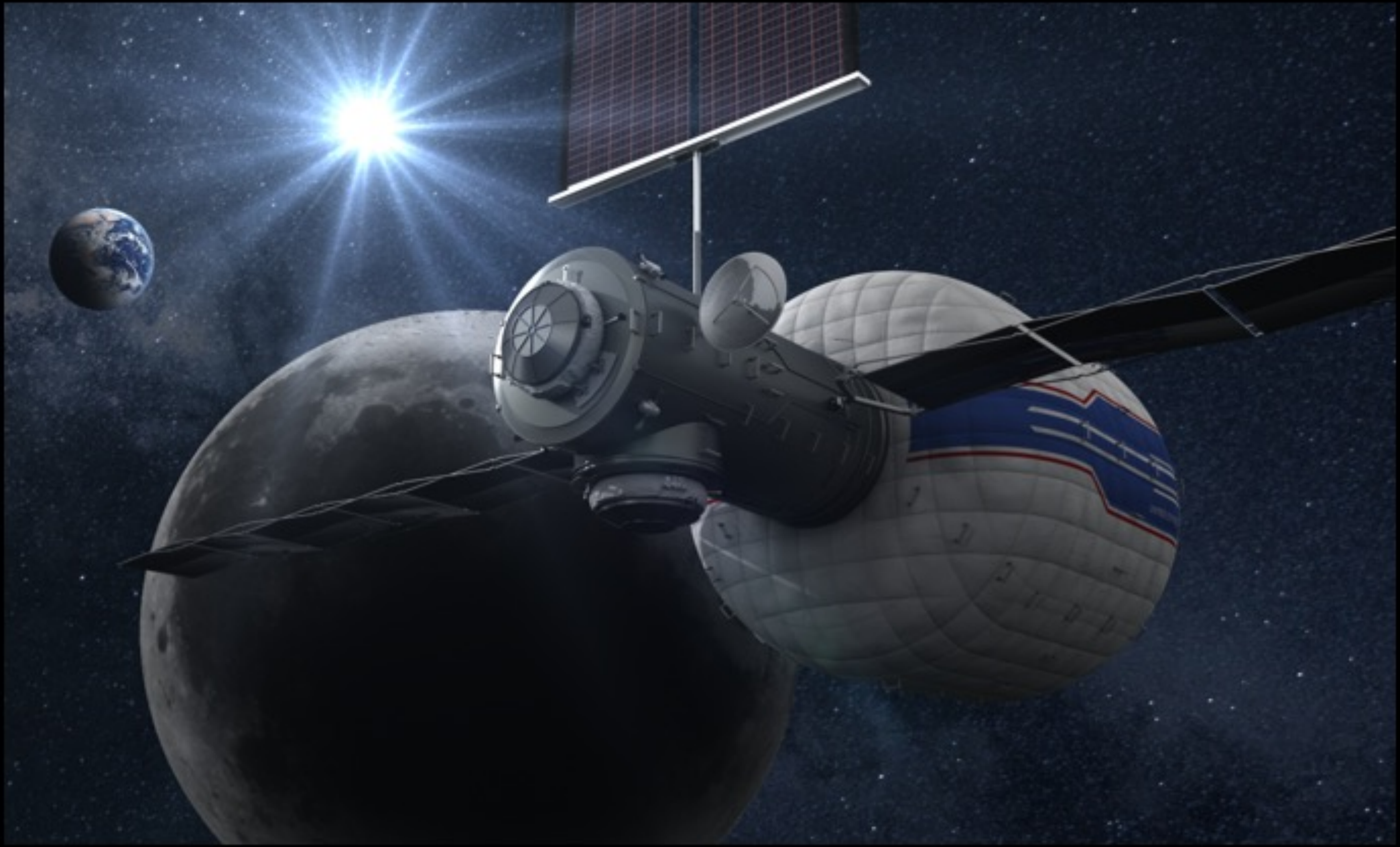
Lunar Surface	5 Hazards of Human Spaceflight	Mars Surface
1/6 Earth Gravity	Altered Gravity	3/8 Earth Gravity
Galactic Cosmic Rays	Radiation	Galactic Cosmic Rays
Different Atmospheres, Environments, Dust	Hostile, Closed Environment	Different Atmospheres, Environments, Dust
Fast Communications, 2-3 Day return	Distance from Earth	20 min Comm. Delay, >9 month return
Small volumes, 2 days-30 days on Surface	Isolation & Confinement	Small volumes,~30 sols on Surface (first mission)

Slide credit: Michelle Rucker, JSC



Slide credit: Michelle Rucker, JSC

Getting There: Mars Transit Habitat



Some Key Technologies Under Consideration

- Inflatable to minimize launched volume
- Lightweight materials and structures
- High availability subsystems such as Life Support with reduced spares mass and increase reliability
- Low mass, low-power, long term food storage
- Long duration, semi-autonomous medical monitoring and care systems
- Lightweight, low power exercise equipment


MARS EXPLORATION OPERATIONS PLAN
The first human mission to Mars will mark a transformative moment for human civilization.
• Supports four crew on the approximate 2-3 year round-trip mission
• Some crew could remain in orbit while some deploy to the surface
MARS TRANSIT VEHICLE (CONCEPT)
POWER AND PROPELLANT
First large mass landed on Mars
CREW ASCENT VEHICLE
PRESSURIZED ROVER
• Delivers crew to the surface
• Provides habitat for 30 days
• Provides mobility for science and exploration operations
ARTIST'S ILLUSTRATION

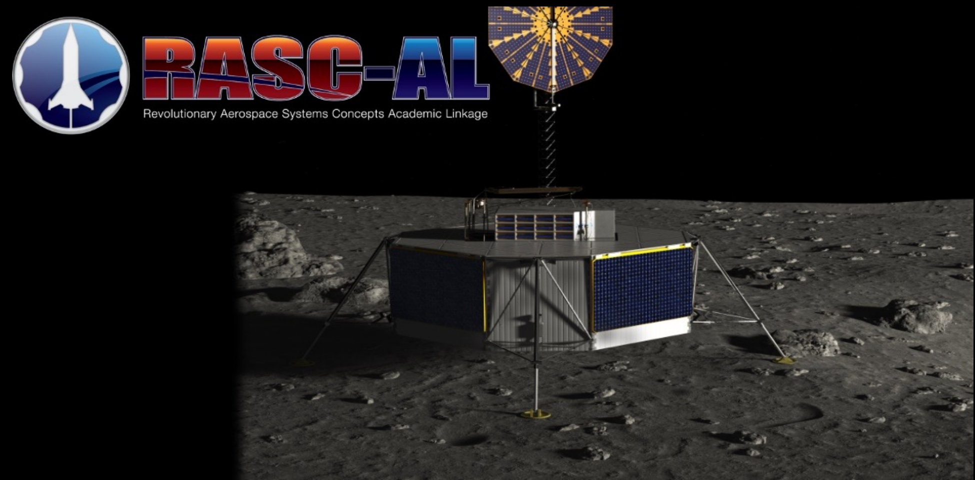

ARTEMIS
ARTEMIS ACCORDS
United for Peaceful Exploration of Deep Space
NASA
ASI
Agenzia Spaziale Italiana
Australian Space Agency
AEB
BRAZILIAN SPACE AGENCY
CSA ASC
JAXA
KARI
LUXEMBOURG SPACE AGENCY
NEW ZEALAND SPACE AGENCY
POLSA
Polish Space Agency
وكالة الإمارات للفضاء
UAE SPACE AGENCY
UK SPACE AGENCY


Social Media
Robotics Designer
Graphic Designer
Astronaut Trainer
Spacesuit Designer
Geologist

#NASAINTERNS
Welding
Technician
Avionics
Technician
NASA
Food
Scientist
Mission Control Center
FLIGHT OPERATIONS
FLIGHT DIRECTOR
Flight Controller
Launch Pad
Construction

Student Opportunities

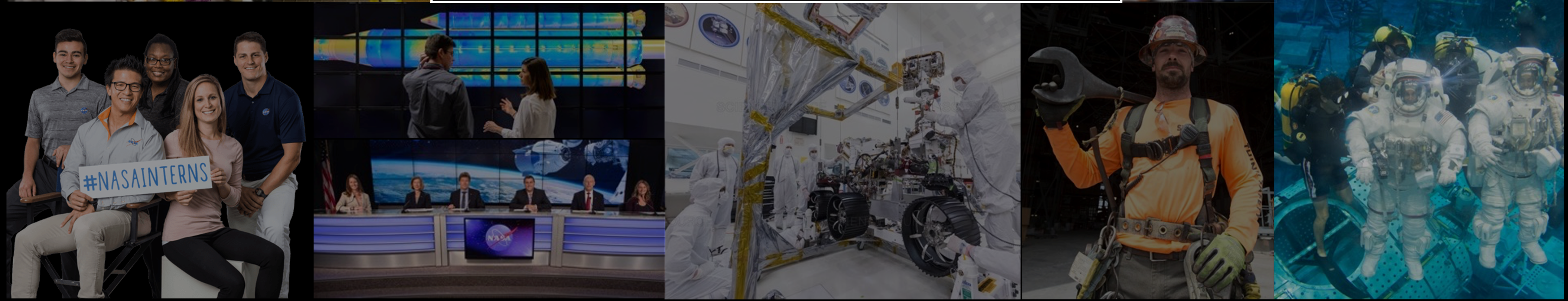
- Internships (intern.nasa.gov)
- XHab
- Big Idea Challenge
- University Student Launch Initiative
- Human Exploration Rover Challenge
- Revolutionary Aerospace Systems Concepts Academic Linkage (RASC-AL)

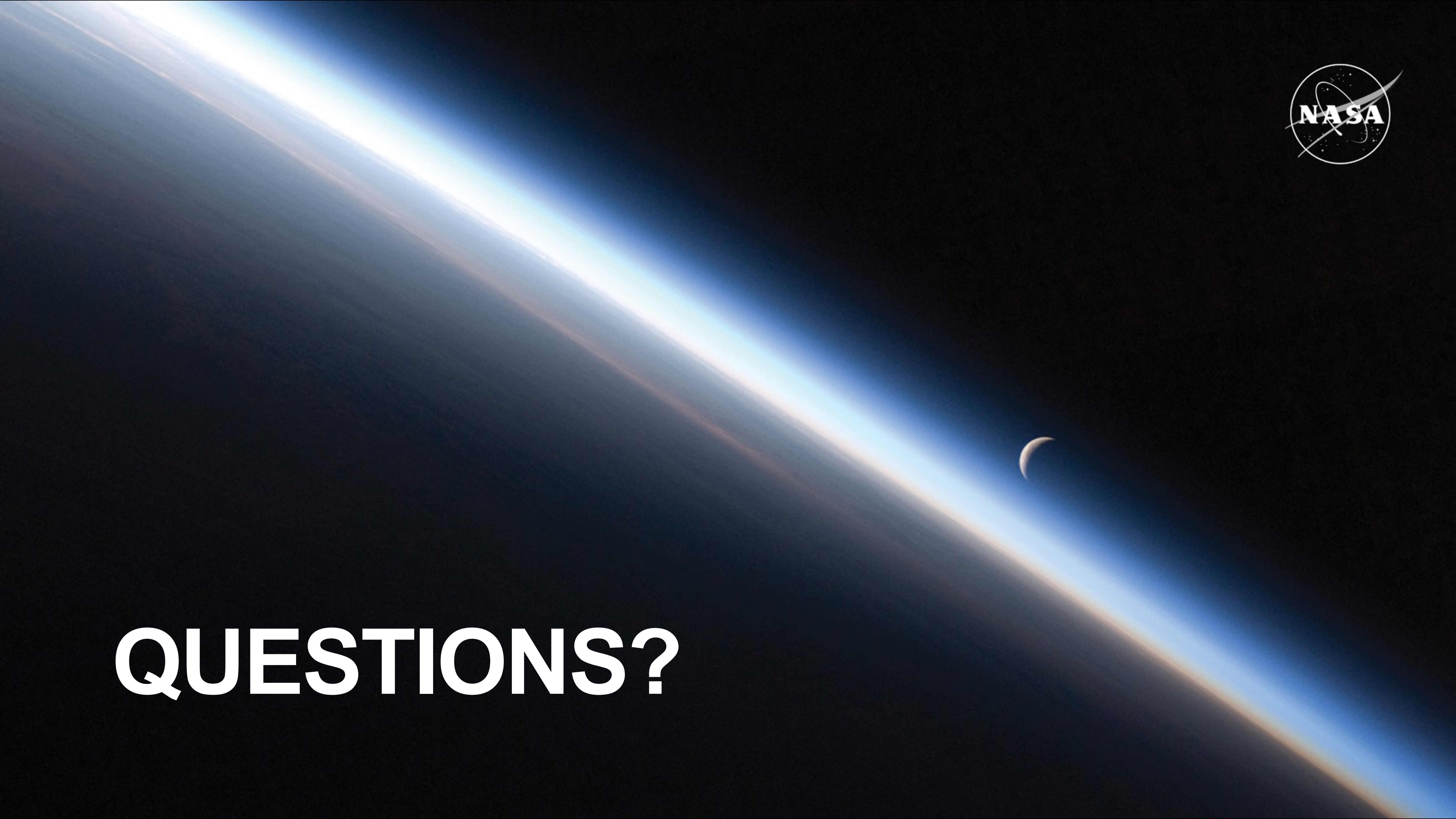


EXPLORATION IS A TEAM SPORT

We have the right plans and the right teams in place to carry our plans forward.

Now we GO.




QUESTIONS?

Back Up Slides and Supplemental Resources

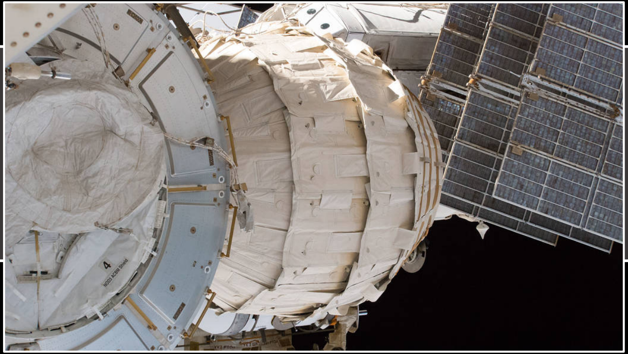
Types of Space Habitats

A class I habitat is a pre-integrated habitat, manufactured and integrated prior to launch

Example: ISS

A class II habitat is pre-fabricated prior to delivery, but deployed in space or on a planetary surface

Example: Inflatable ISS BEAM module



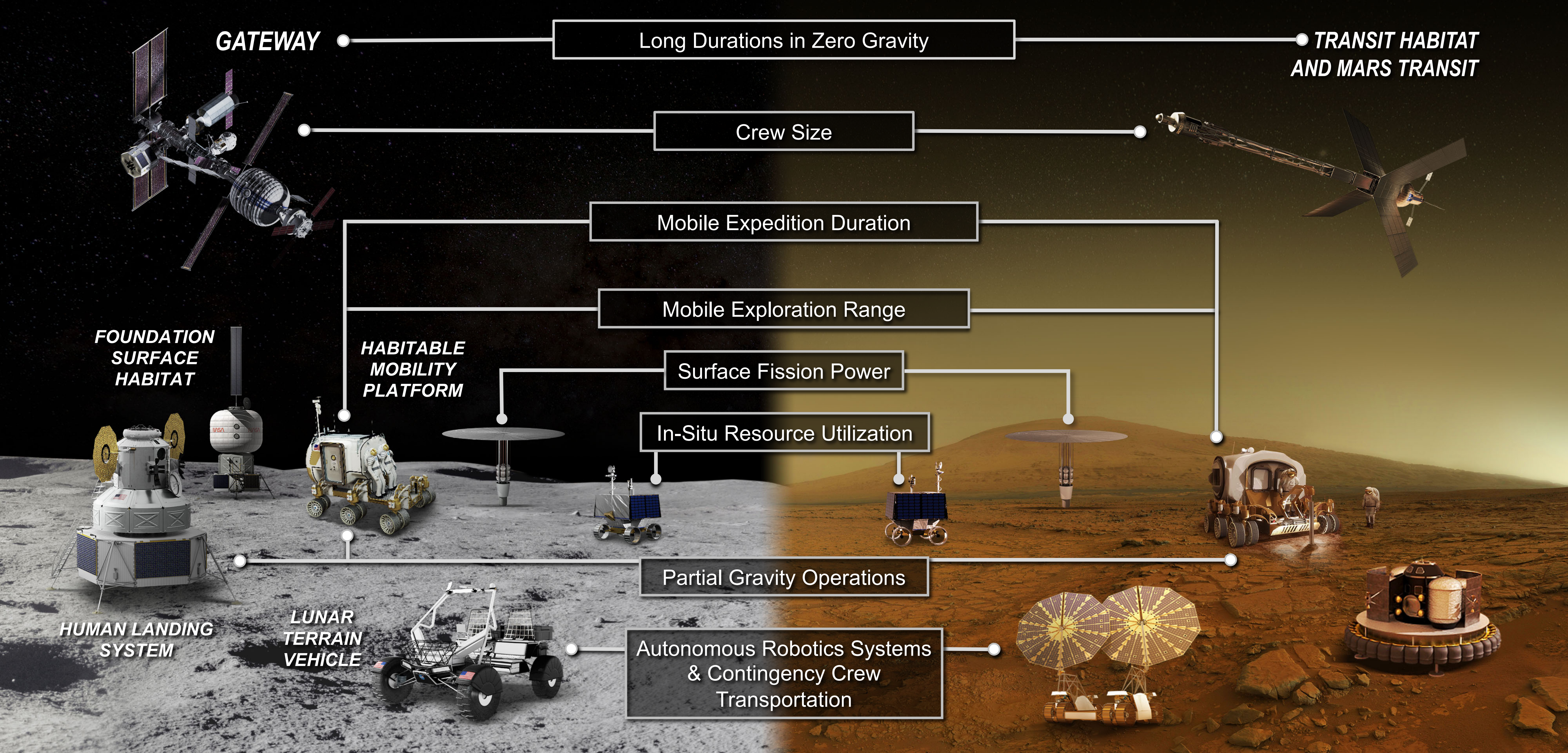
A class III habitat is built in situ using local resources

Example: 3D Printed Habitat on planetary surface

Image from ICON and SEArch+.

MOON AND MARS EXPLORATION

Operations on and around the Moon will help prepare for the first human mission to Mars



Lunar Missions Prepare Us for Mars

IN ORBIT

DEEP SPACE AGGREGATION
Assembling a complex ship in deep space

MARS TRANSIT HABITAT
Round the clock, years-long operations of a Mars-class habitat and life support system

ORBIT TO SURFACE OPERATIONS
Operating an orbiting outpost that deploys a lander and its crew to a planetary surface

COMMERCIAL RESUPPLY AND REFUELING
Leveraging the space logistics supply chain for industry provided cargo deliveries

CREW HEALTH & PERFORMANCE
Studying how the human body and mind adapt to deep space hazards

A roundtrip mission to Mars will take about two years—and once the ship's course is set, there's no turning back.

As much as is possible, lunar systems will be designed for dual Moon-Mars operations.

Integrated missions in the lunar vicinity prepare us for successful Mars missions

ON THE SURFACE

SPACESUIT ADVANCEMENTS
Improving spacesuit design across Artemis missions with astronaut input and private sector innovation

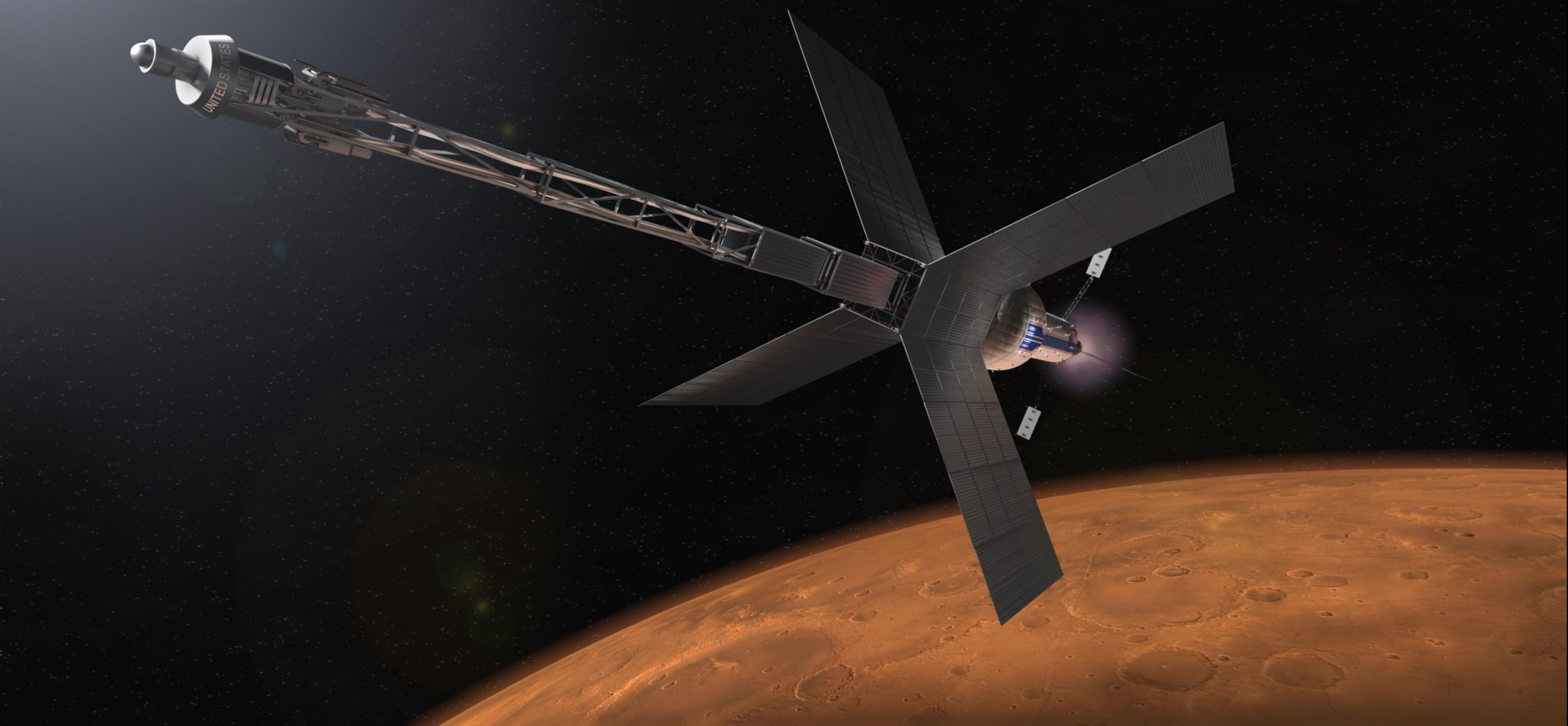
MOBILE OPERATIONS
Living and working 'on the go' inside a mobile habitat for weeks at a time

PLANETARY PROTECTION
Mitigating dust transfer and establishing pristine sample curation protocols

HUMAN ROBOTIC EXPLORATION
Robots pre-positioning surface assets and conducting reconnaissance for astronauts

HUMAN RESILIENCE
Learning how humans can survive and thrive in a partial gravity environment

MARS TRANSIT HABITAT



Transit Habitat

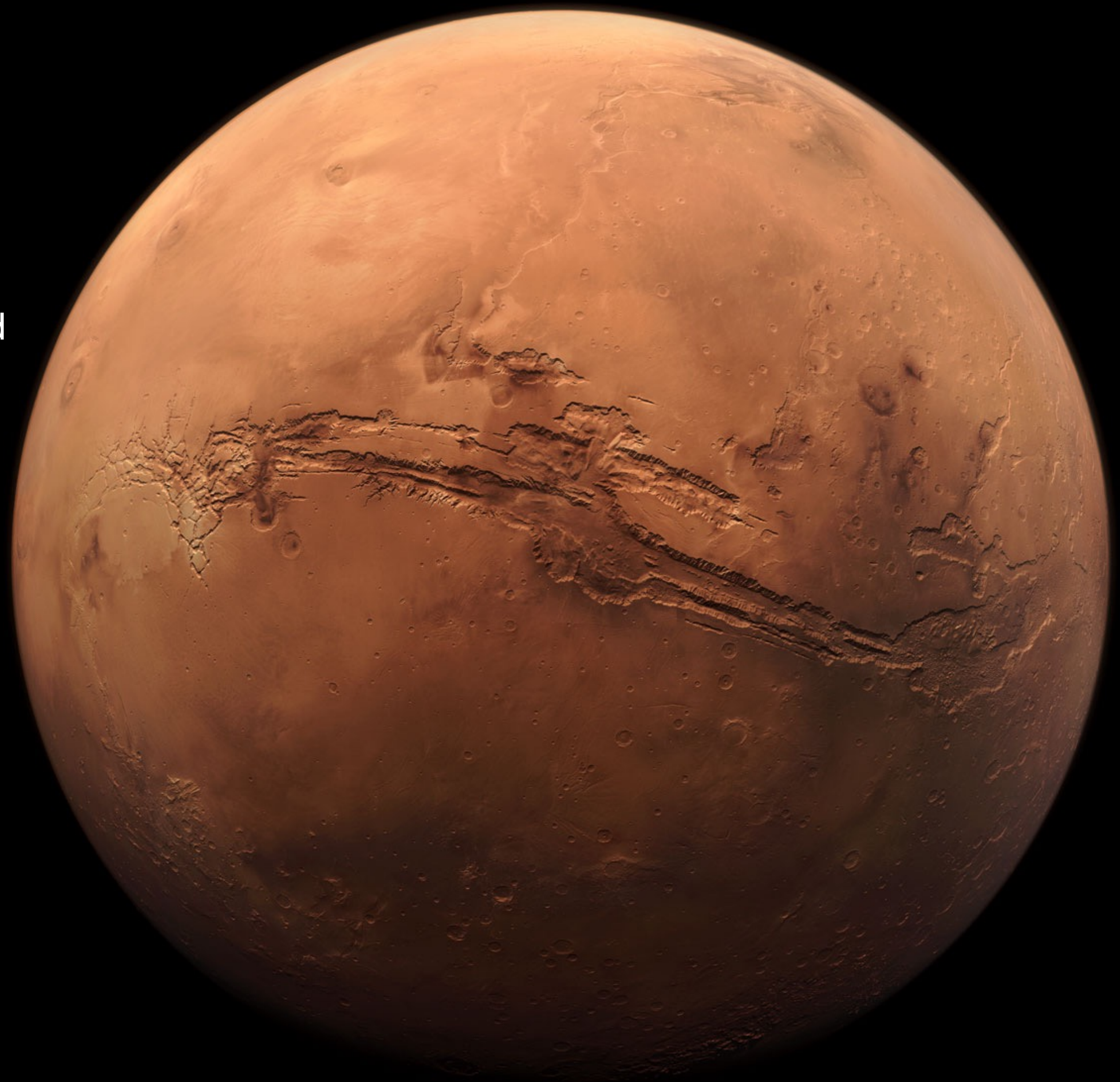
Objective:

- A primary asset to transport crew to and from Mars. Early mission serve as a platform for Mars Mission preparations
- NASA is working with industry to enable conceptual designs for the Transit Habitat

Capabilities:

- Series of Lunar-Mars analog and shakedown missions with 4 crew leading to a Mars mission of up to 1,110 days
- Docked at Gateway upon initial deployment for shakedown
- Re-used for multiple missions over 15 year lifetime
- Builds on ISS and commercial investment in deep space habitation

Transit Habitat | Challenges

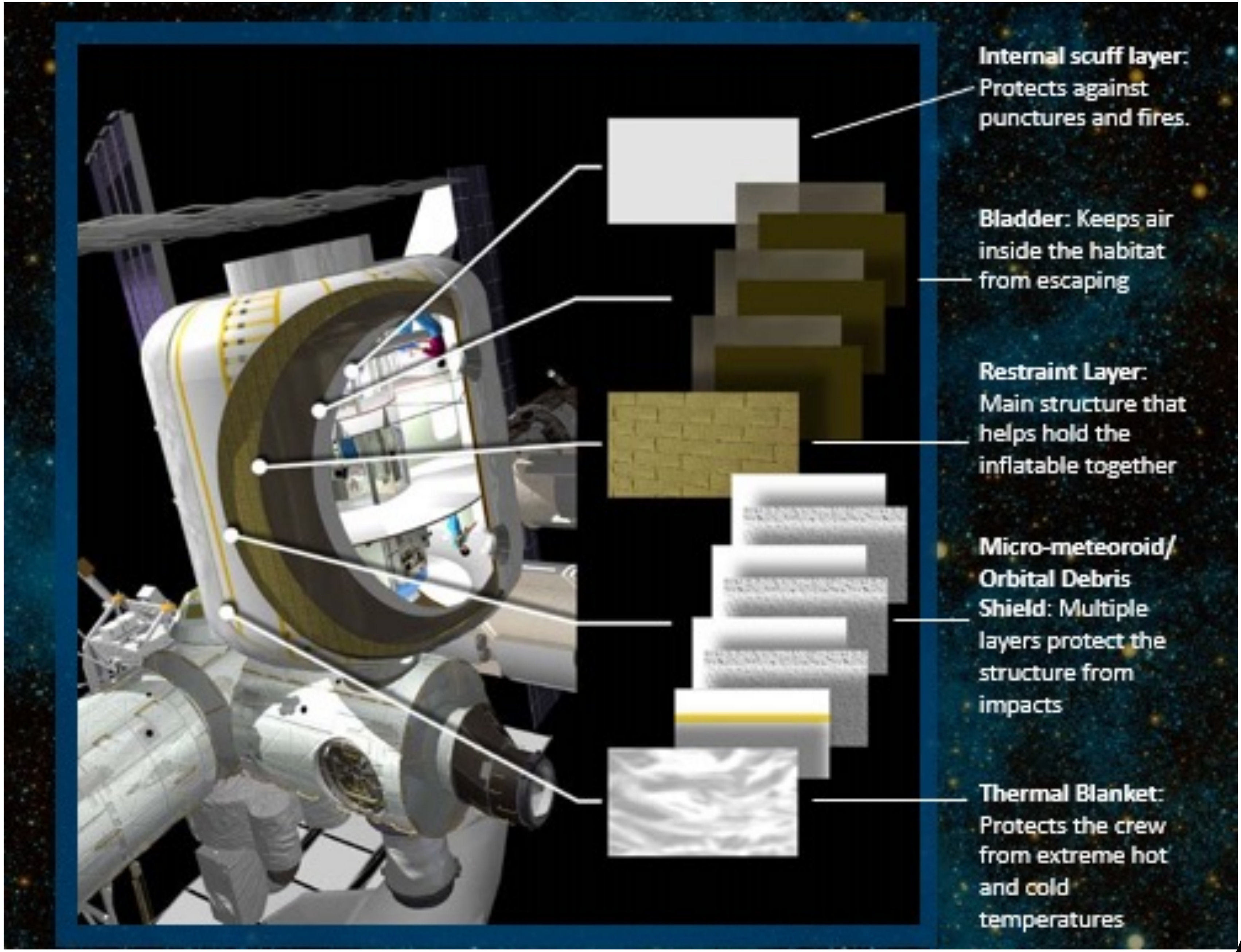


- No spares resupply chain during transit without on-demand manufacturing capabilities
- Logistics storage capacity for mission
- Waste management and trash management in transit
- Radiation & MMOD protection
- Communication delays
- Ability to recover from major habitation failures
- Autonomous avionics
- Human health and performance for long duration missions

Materials for Inflatable Space Habitats

Inflatable space habitats consist of lightweight layers of multiple materials. They can be packed compactly for launch and inflated at their destination.

The multiple layers of an inflatable structure allow it to protect astronauts from small meteorites, radiation and the extreme heat and cold of space.

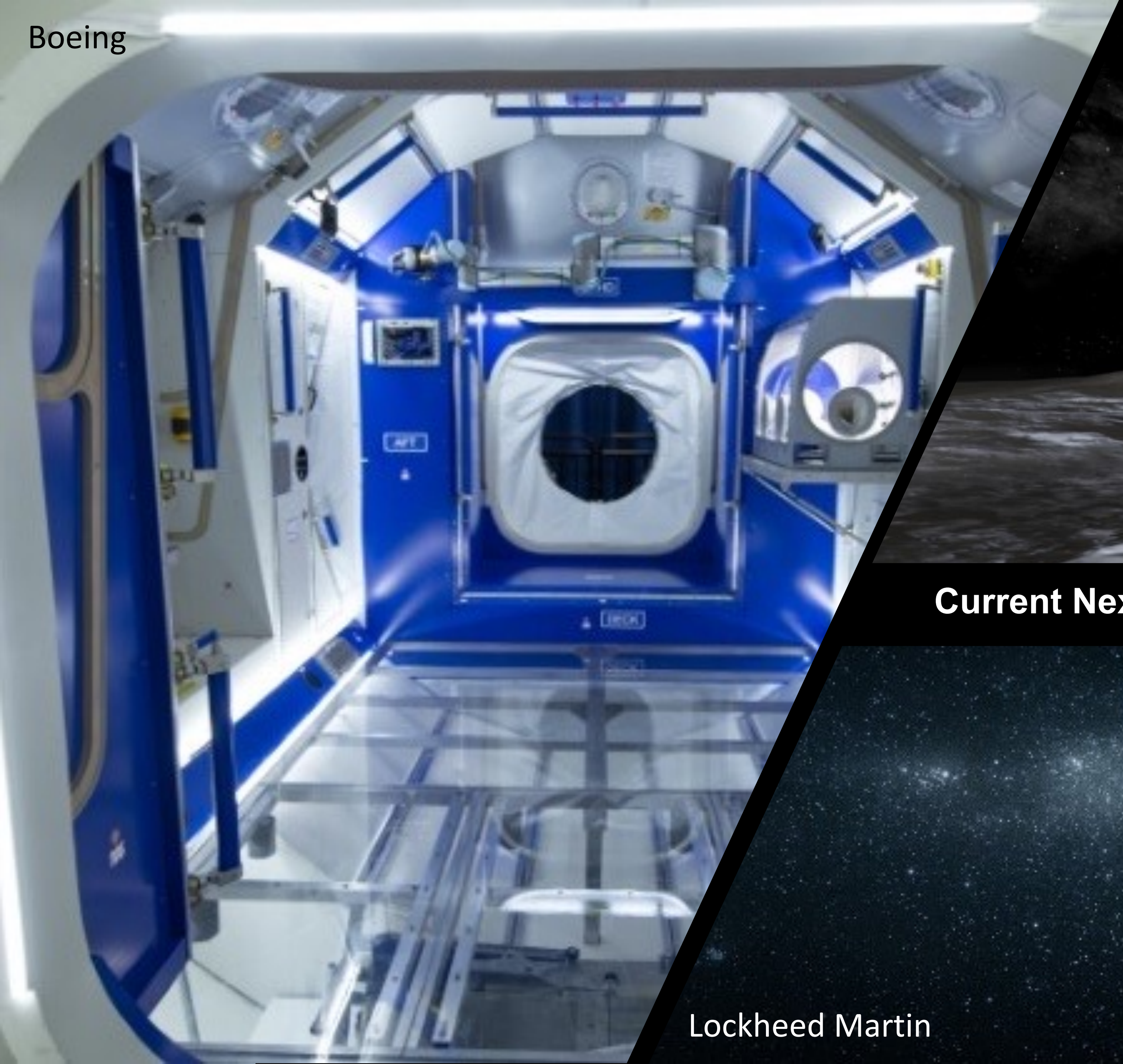


Inflatable Material System

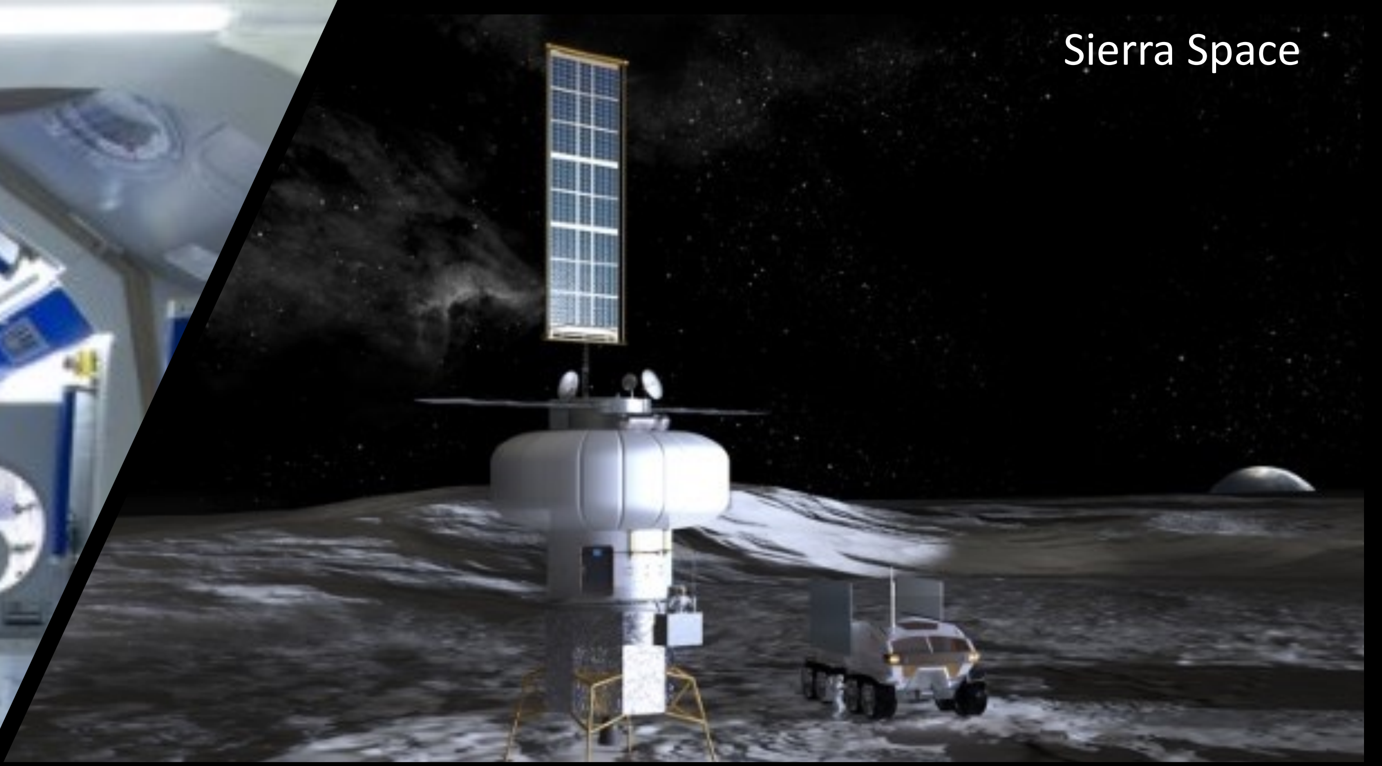
Commercial Partners

NextSTEP Appendix A: Habitation Systems

Phase 1 – 2015-2016: Concept Designs and Operations
Phase 2 – 2016-2019: Prototype Development and Testing
Phase 3 – 2019-2021: Concept maturation and focus on long-duration, in-space and surface habitats



Boeing



Sierra Space

Current NextSTEP Appendix A commercial partners

Lockheed Martin






Marshall Space Flight Center History

"Rocket City" Fast Stats

2nd largest research park

2nd largest concentration of high-tech workers

Highest concentration of degreed engineers

#1 best place for STEM workers

Top 10 city for Career Opportunities

Redstone Arsenal

41,000 employees

$50B in annual Federal budgets

Marshall's Community


ARTEMIS
WE ARE GOING
TWENDE NADHHAB IDZIEMY ONS GAAN
NOSOTROS VAMOS NÓS VAMOS
WIR GEHEN UNLINEUN GANDA
KITA PERGI WATASHITACHIHA IKU

Artemis: a Foundation for Deep Space Exploration

Space Launch System

Orion spacecraft

Human Landing System

Surface Operations

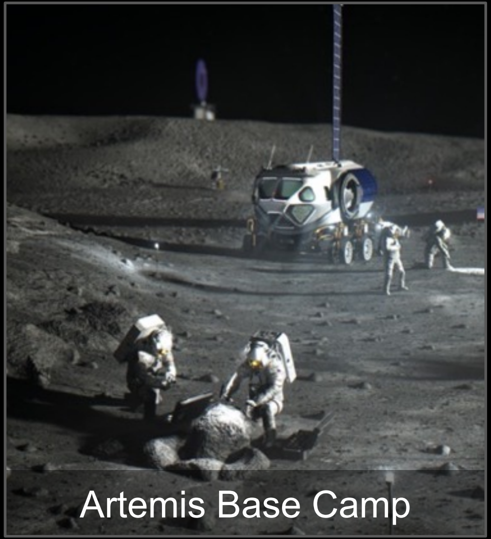
Gateway

Exploration Ground Systems

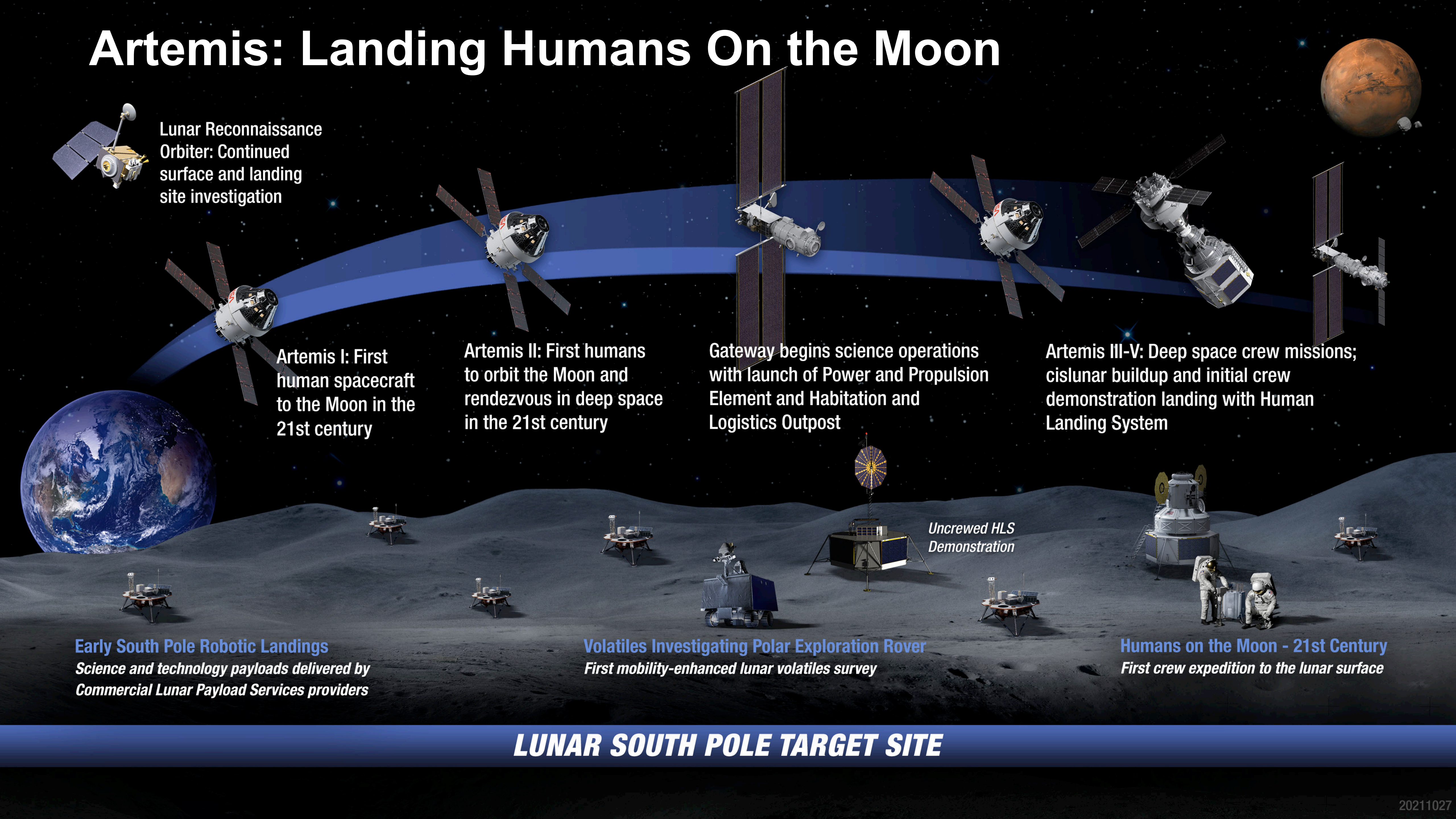
Space Communications & Navigation

Surface Mobility

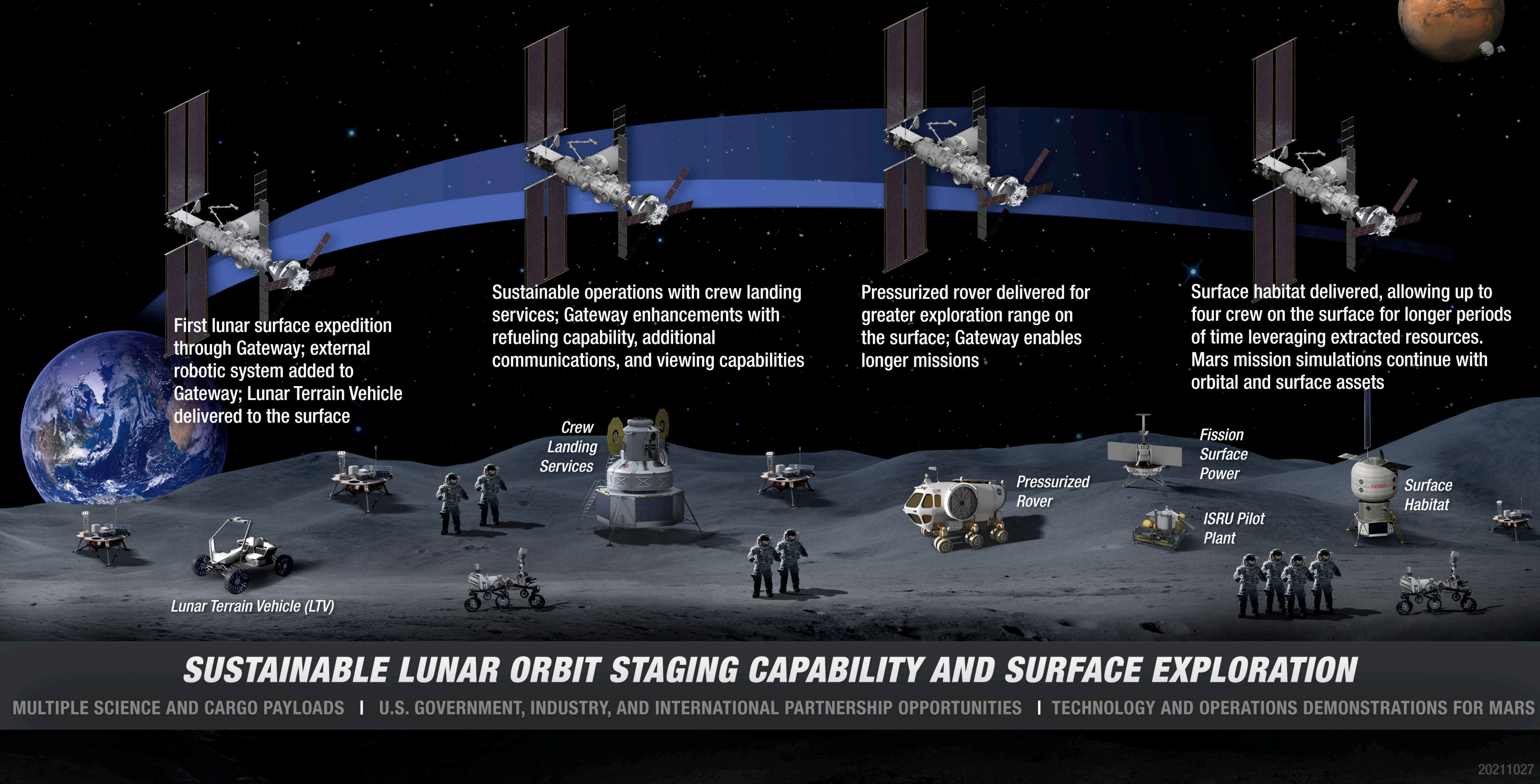
Space Suits



Artemis Base Camp


Artemis: Landing Humans On the Moon
Lunar Reconnaissance Orbiter: Continued surface and landing site investigation
Artemis I: First human spacecraft to the Moon in the 21st century
Artemis II: First humans to orbit the Moon and rendezvous in deep space in the 21st century
Gateway begins science operations with launch of Power and Propulsion Element and Habitation and Logistics Outpost
Artemis III-V: Deep space crew missions; cislunar buildup and initial crew demonstration landing with Human Landing System
Uncrewed HLS Demonstration
Early South Pole Robotic Landings
Science and technology payloads delivered by Commercial Lunar Payload Services providers
Volatiles Investigating Polar Exploration Rover
First mobility-enhanced lunar volatiles survey
Humans on the Moon - 21st Century
First crew expedition to the lunar surface
LUNAR SOUTH POLE TARGET SITE
20211027

Artemis Base Camp Buildup

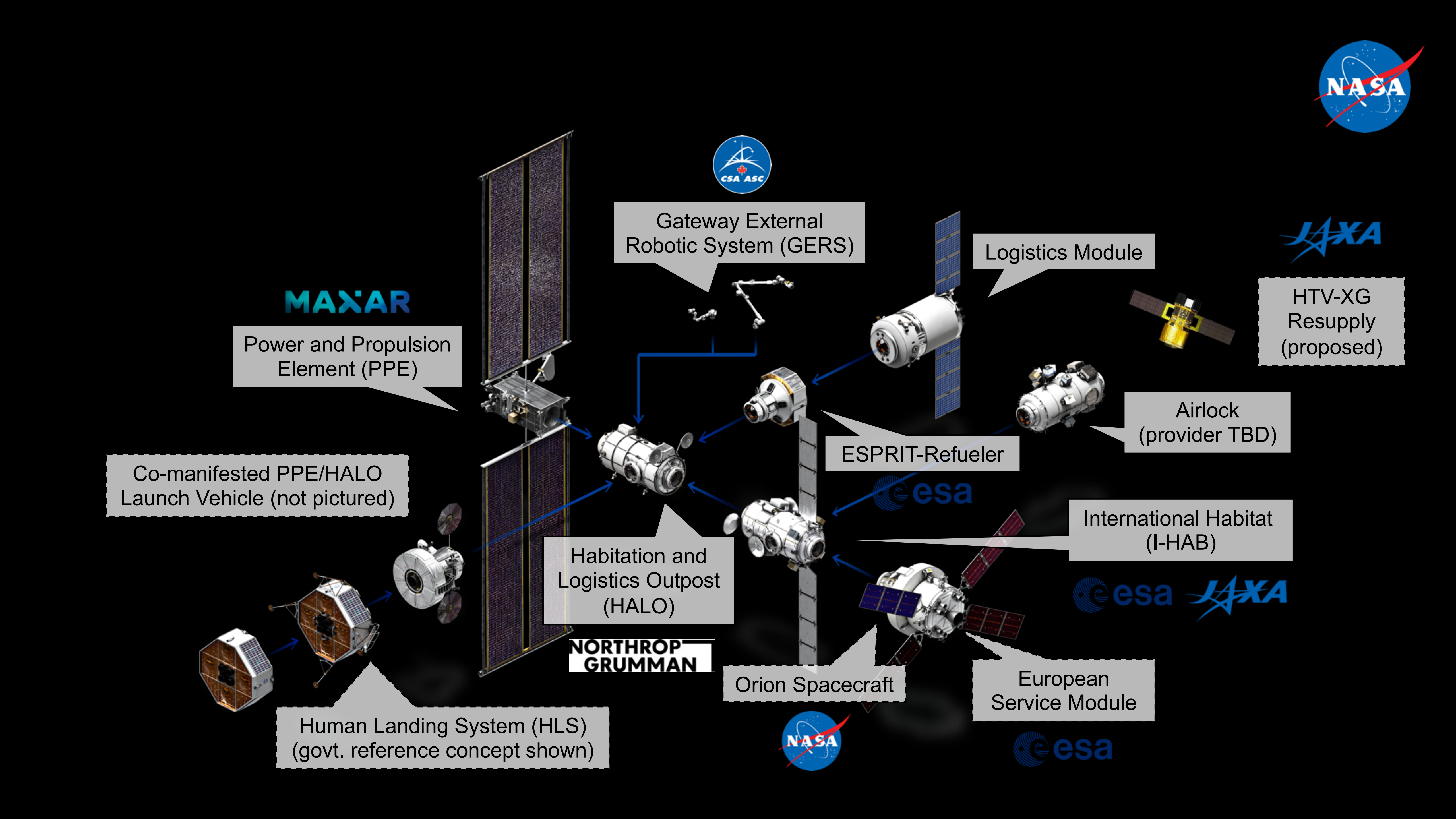



United States
SLS


ORION


EGS
NASA
ARTEMIS


GATEWAY
NASA
CSA ASC
esa
JAXA



Gateway External Robotic System (GERS)
Logistics Module
HTV-XG Resupply (proposed)
Power and Propulsion Element (PPE)
Airlock (provider TBD)
ESPRIT-Refueler
Co-manifested PPE/HALO Launch Vehicle (not pictured)
International Habitat (I-HAB)
Habitation and Logistics Outpost (HALO)
Human Landing System (HLS) (govt. reference concept shown)
Orion Spacecraft
European Service Module

Human Landing System

SpaceX: First Crew Demonstration landing on Artemis III

Artist's illustration

Transports astronauts from lunar orbit to the lunar surface and back up to lunar orbit

- Carries two crew on early missions, growing up to four crew as capabilities grow
- On early missions, the lander itself will double as the crew's habitat
- NASA plans to procure lunar lander services from U.S. companies, much like the agency does for crew and cargo deliveries to the International Space Station
- The Gateway in lunar orbit has multiple docking ports to accommodate the lander, crew arriving in Orion, and cargo supply deliveries all at the same time.

Unpressurized Rover

Lunar Terrain Vehicle

Artist's illustration

Provides early mobility for suited Artemis astronauts to expand exploration range.

- Reusable and rechargeable for approximate 10-year service life
- Remote operation from HLS, Gateway, Earth
- Ability to traverse from one landing zone to another
- Interface with future science instruments and payloads for utilization or pre-deployment of assets
- Ability to survive eclipse periods

Pressurized Rover

Artist's illustration

Provides pressurized mobile habitation to enable long-range surface exploration in shirtsleeve environment and quick and easy access to surface.

- Habitation for 30 days for 2 crew
- Rear suitport allows astronaut egress and ingress of the vehicle via the spacesuits, leaving the suits outside the pressurized volume
- Provides volume for spares and logistics
- Power generation and energy storage for lunar environment
- Dust and radiation protection
- Reuse for multiple missions of 15-year lifetime
- Capability also identified in current concepts for first human mission to Mars

Surface Habitat

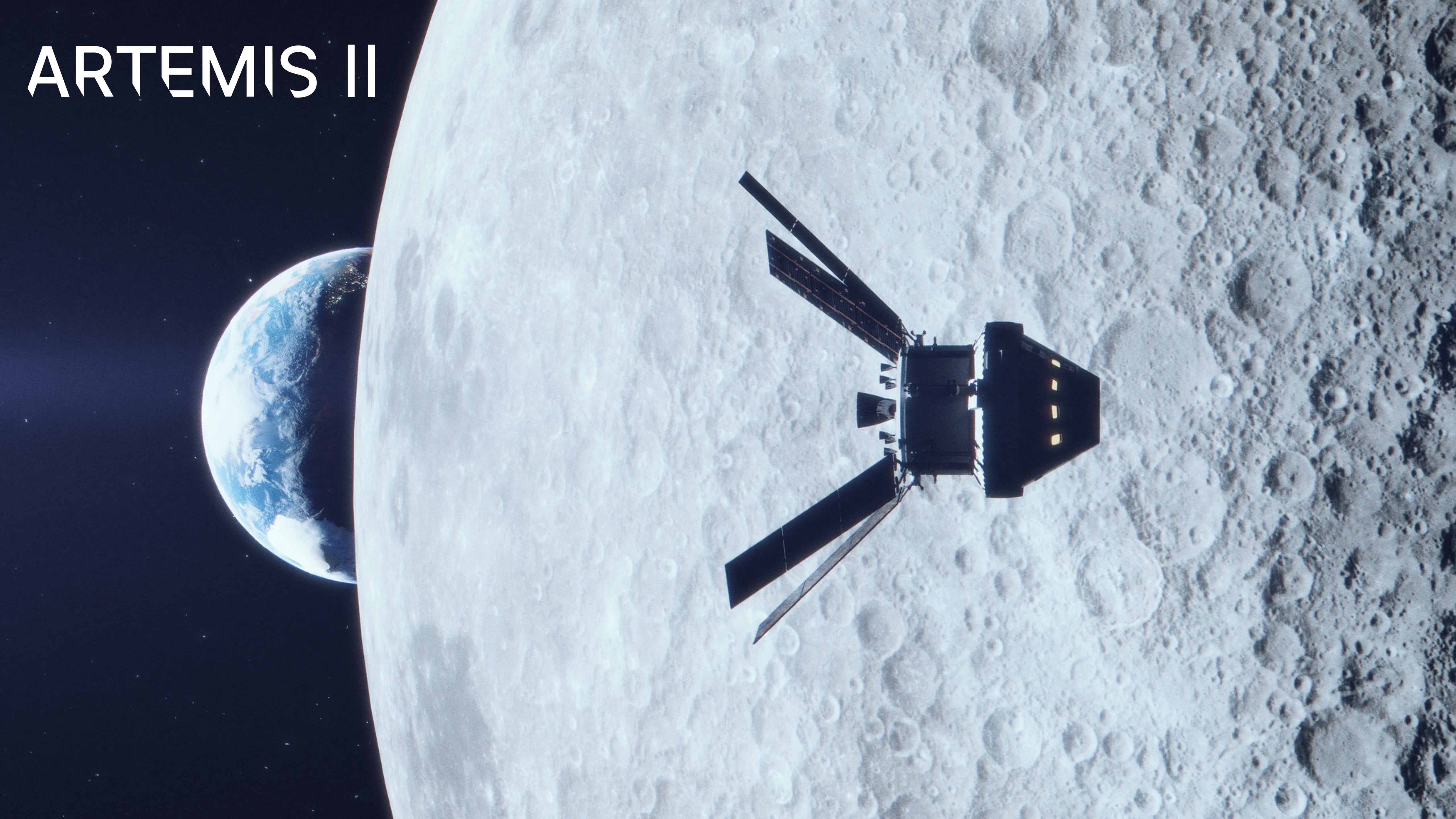
Artist's illustration

Will be a primary asset to achieve a sustained lunar presence.

NASA is working with industry to develop conceptual designs for the Foundational Surface Habitat.

- 2-4 crew – medical, exercise, galley, crew quarters, stowage
- 30-60 day capable habitat
- EVA capable via air lock with suit maintenance capability
- Power generation, recharge capability for surface assets
- Communication hub for surface assets
- Reuse for multiple missions of 15 year lifetime

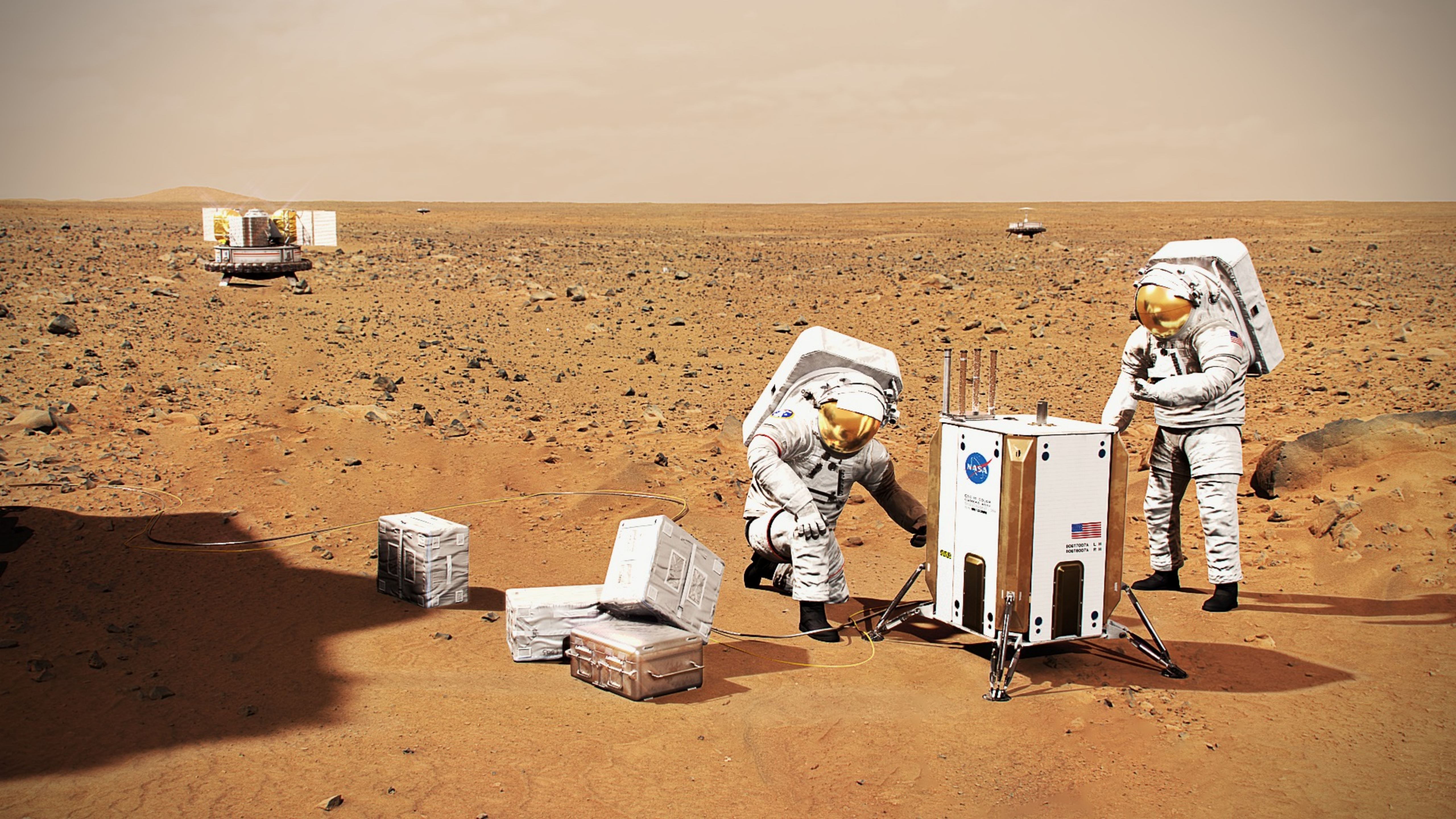

ARTEMIS I

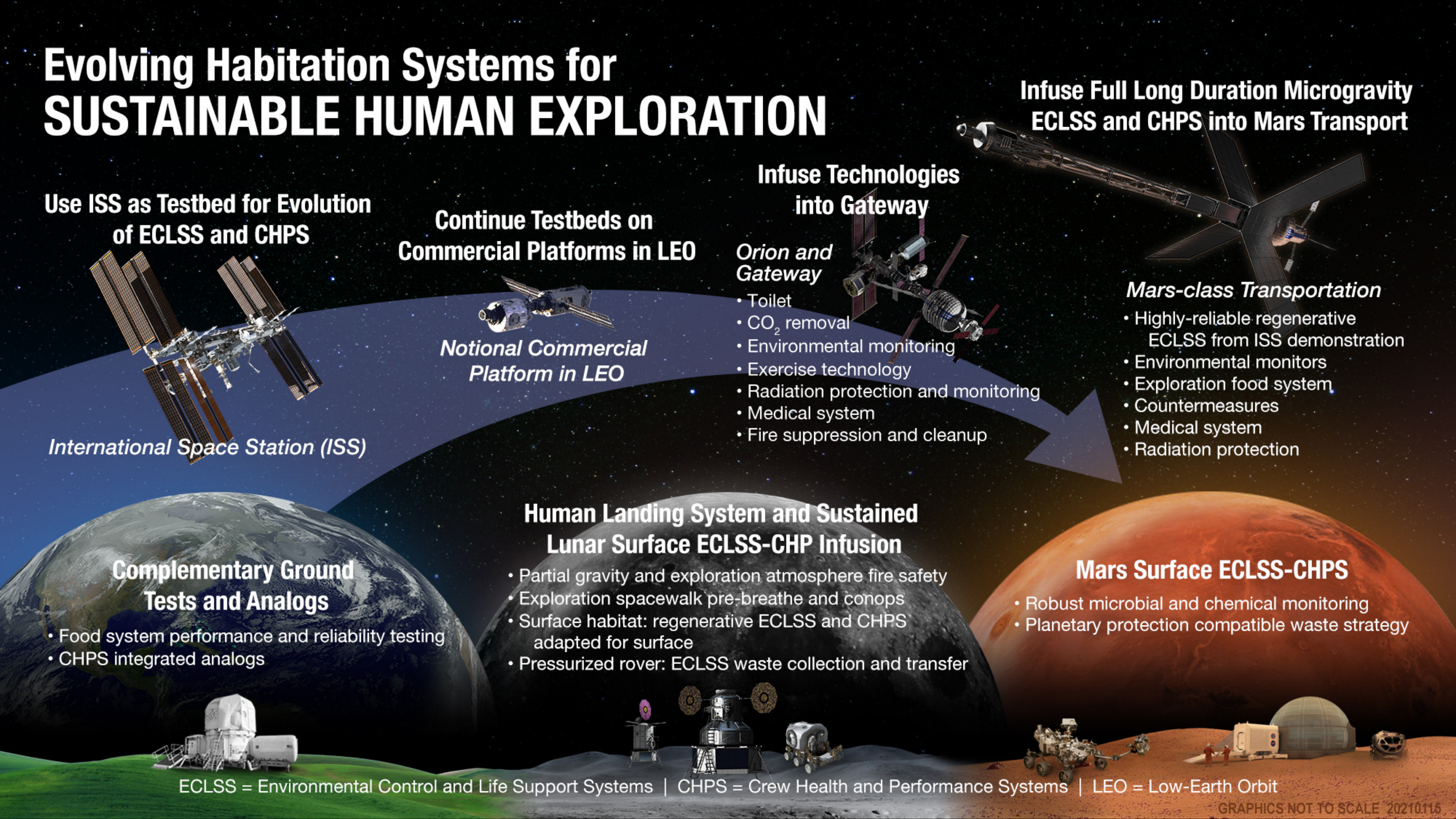

ARTEMIS II

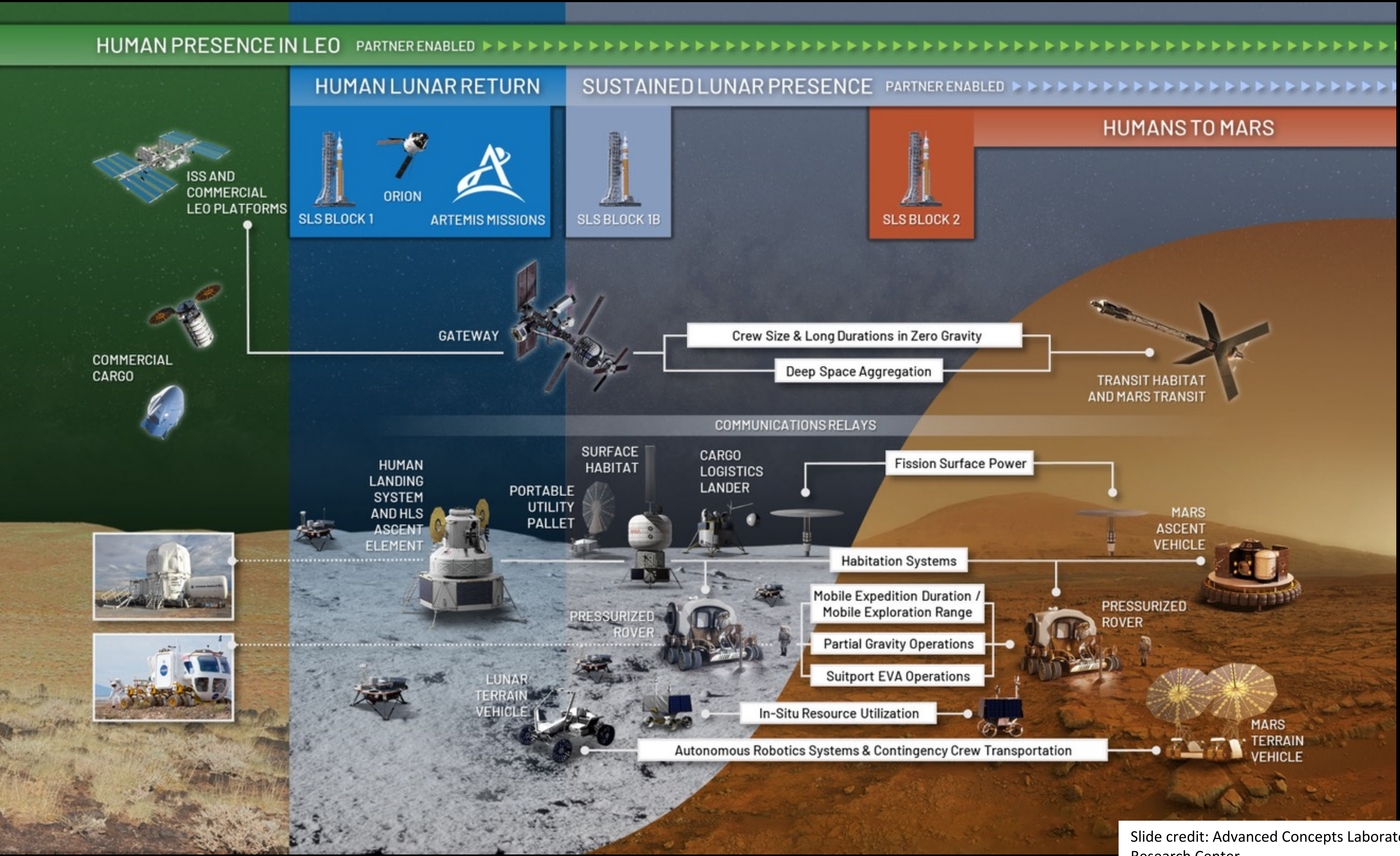

Mode Norm
RHC Pwr: On
Pitch
Yaw
Roll
Switch 1 Auto
Switch 2
Switch 3
Switch 4
THC Pwr: On
Survival Pyros
CAUTION


NASA
Joseph ACABA
Kayla BARRON
Raja CHARI
Matthew DOMINICK
Victor GLOVER
Warren HOBURG
Jonny KIM
Christina H. KOCH
Kjell LINDGREN
Nicole A. MANN
Anne McCLAIN
Jessica MEIR
Jasmin MOGHBELI
Kate RUBINS
Frank RUBIO
Scott TINGLE
Jessica WATKINS
Stephanie D. WILSON


ARTEMIS III


NASA


Evolving Habitation Systems for
SUSTAINABLE HUMAN EXPLORATION
Use ISS as Testbed for Evolution of ECLSS and CHPS
International Space Station (ISS)
Continue Testbeds on Commercial Platforms in LEO
Notional Commercial Platform in LEO
Infuse Technologies into Gateway
Orion and Gateway
• Toilet
• CO_2 removal
• Environmental monitoring
• Exercise technology
• Radiation protection and monitoring
• Medical system
• Fire suppression and cleanup
Infuse Full Long Duration Microgravity ECLSS and CHPS into Mars Transport
Mars-class Transportation
• Highly-reliable regenerative ECLSS from ISS demonstration
• Environmental monitors
• Exploration food system
• Countermeasures
• Medical system
• Radiation protection
Complementary Ground Tests and Analogs
• Food system performance and reliability testing
• CHPS integrated analogs
Human Landing System and Sustained Lunar Surface ECLSS-CHP Infusion
• Partial gravity and exploration atmosphere fire safety
• Exploration spacewalk pre-breathe and conops
• Surface habitat: regenerative ECLSS and CHPS adapted for surface
• Pressurized rover: ECLSS waste collection and transfer
Mars Surface ECLSS-CHPS
• Robust microbial and chemical monitoring
• Planetary protection compatible waste strategy
ECLSS = Environmental Control and Life Support Systems | CHPS = Crew Health and Performance Systems | LEO = Low-Earth Orbit
GRAPHICS NOT TO SCALE 20210115



Slide credit: Advanced Concepts Laboratory, NASA Langley Research Center

TERRESTRIAL

Habitat prototyping using NASA experts and facilities. Full scale habitat mockup testing with NASA-private sector teams.

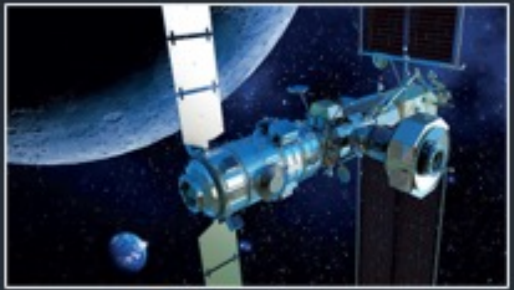
Mission simulations. High-fidelity end-to-end crewed analog missions at extreme locations on Earth.

LOW-EARTH ORBIT

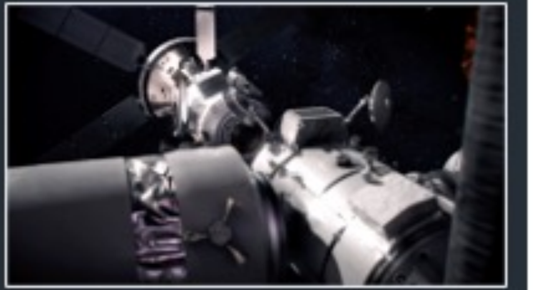
Low-Earth orbit demos. Bigelow Expandable Activity Module (BEAM) soft-goods risk reduction demo at ISS.

Habitation system upgrades validating deep space capabilities. Advanced ECLSS systems validated on ISS before deep space.

CISLUNAR



Long-term habitation in lunar orbit. HALO and I-Hab modules on the Gateway will demonstrate long-duration, deep space habitation capabilities.



Deep space operations. Spacecraft aggregation and resupply, communications, and orbit maintenance for global access to the Moon.

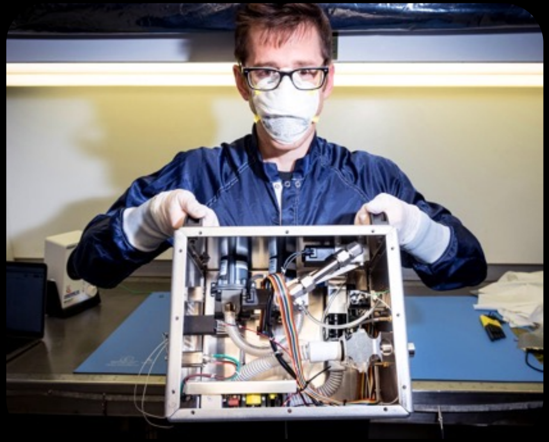
LUNAR SURFACE

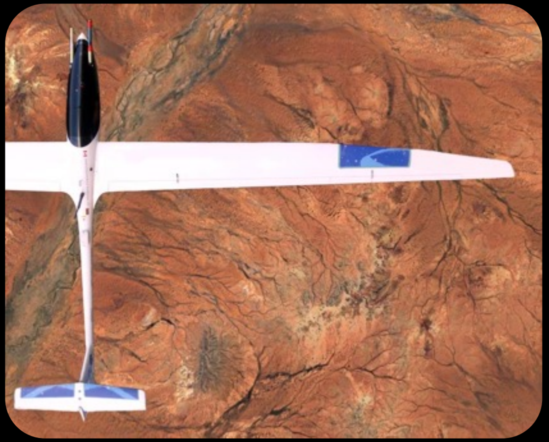
Mobile habitation on the Moon. Pressurized rover on the surface will greatly expand crew exploration range and demo Mars-forward capability.

Fixed lunar surface habitation. Anchor for long-term, human-led exploration at the lunar South Pole.

FEED FORWARD TO MARS

- Save lives
- Make the planet cleaner
- Create jobs
- Educate and entertain
- Help small businesses
- And more



A Global Community

International partnerships are critical to the next era of human exploration and expansion

- Artemis Accords
- Gateway MOUs
- Scientific collaborations

These are just some examples of how we're collaborating. NASA is actively seeking opportunities to partner with other nations as Artemis grows.

Pictured left: Republic of Korea Minister of Science and ICT Lim Hyesook signs the Artemis Accords.

The Artemis Accords

Principles for a Safe, Peaceful, and Prosperous Future

PEACEFUL PURPOSES
Conduct activities for peaceful purposes, per the tenets of the Outer Space Treaty

EMERGENCY ASSISTANCE
Provide emergency assistance to those in need

SPACE RESOURCES
Extract and use space resources under the auspices of the Outer Space Treaty

TRANSPARENCY
Publicly describe space polices and plans in a transparent manner

REGISTRATION OF SPACE OBJECTS
Join the Registration Convention and register public and private activities in space to avoid harmful interference

DECONFLICTION OF ACTIVITIES
Provide public information about the location and general operations of activities on the Moon to inform scale and scope of ‘safety zones’

INTEROPERABILITY
Use open international standards and support interoperability

RELEASE OF SCIENTIFIC DATA
Release scientific data publicly to ensure the entire world can benefit from space exploration and discovery

ORBITAL DEBRIS AND SPACECRAFT DISPOSAL
Plan for the mitigation of orbital debris

Constructed Habitats

Moon-to Mars Planetary Autonomous Construction Technologies (MMPACT) Overview

GOAL

Develop, deliver, and demonstrate on-demand capabilities to protect astronauts and create infrastructure on the lunar surface via construction of landing pads, habitats, shelters, roadways, berms and blast shields using lunar regolith-based materials.

APPROACH

MMPACT is comprised of 3 interrelated elements

- Olympus – Autonomous Construction System
- Construction Feedstock Materials Development
- Microwave Structure Construction Capability (MSCC)

High Level Capability Gaps (including those identified by the LSII Formulation Guidance for Lunar Surface Construction):

- Deposition processes and associated materials
- Increased autonomy of operations
- Hardware operation and manufacturing under lunar environmental conditions
- Long-duration operation of mechanisms and parts
- Scale of construction activities
- Material and construction requirements and standards

Slide from Dr. Jennifer Edmunson, NASA MSFC

Lunar In Situ Resource Utilization-based Habitats will be expected to meet a wide variety of environmental requirements

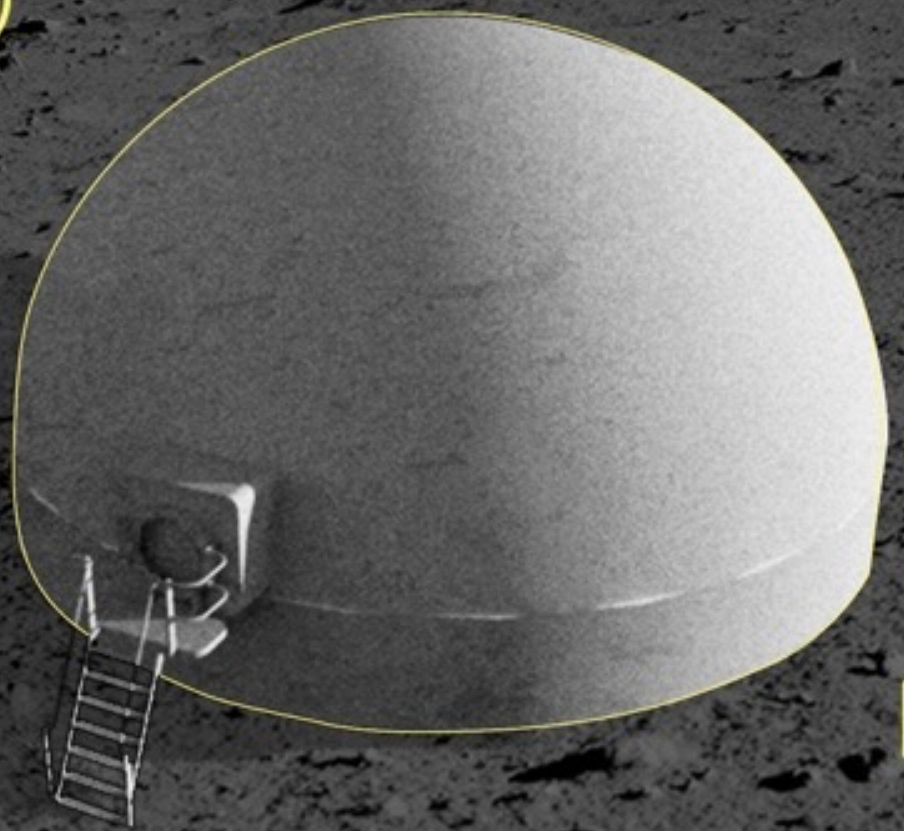
RADIATION

- Galactic Cosmic Rays (GCRs)
- Solar Particle Events (SPEs)
- Secondary Particles
- Albedo

MMPACT

METEOROID IMPACT

- Robust & durable shielding required. Composites and ballistic shielding preferred.
- Consideration of new failure modes due to impact
- Dust ramifications



SEISMIC ACTIVITY

- Deep Moonquakes lasting hours, even days
- Seismic Effects of Meteor Impacts

EXTREME TEMPERATURES

- Extreme Material Stresses
- Structural & Material Fatigue

Image courtesy of SEArch+

Slide from Dr. Jennifer Edmunson, NASA MSFC

Architectural Design Strategies for Risk Mitigation

MMPACT

RADIATION	SEISMIC ACTIVITY	EXTREME TEMPERATURES	METEOROID IMPACT
Shielding Mass & Thickness for Attenuation	Base Dampening & Isolation	High-Yield & Elastic Materials	Ballistic Robustness & Durability
Hydrogen-Rich Materials	Structural Reinforcement	Heat Transfer Strategies	Structural Reinforcement
Crew Operational Parameters; Habitat Protectiveness		Expansion Joints	Whipple Shields
			Structural Monitoring; Sensor Networks & Probabilistic Risk Assessment

Slide from Dr. Jennifer Edmunson, NASA MSFC

Materials for Lunar Landing Pads and Habitats

- Developing materials for specific applications (landing pads, roads, habitats)
- Evaluating materials based on the environment in which they will perform
  - Vacuum, temperature swings, rocket engine plume, durability/longevity
- Growing the area of Outfitting, utilizing available in-situ resources


Image from ICON and Search+


Image from ICON and Bjarke Ingels Group

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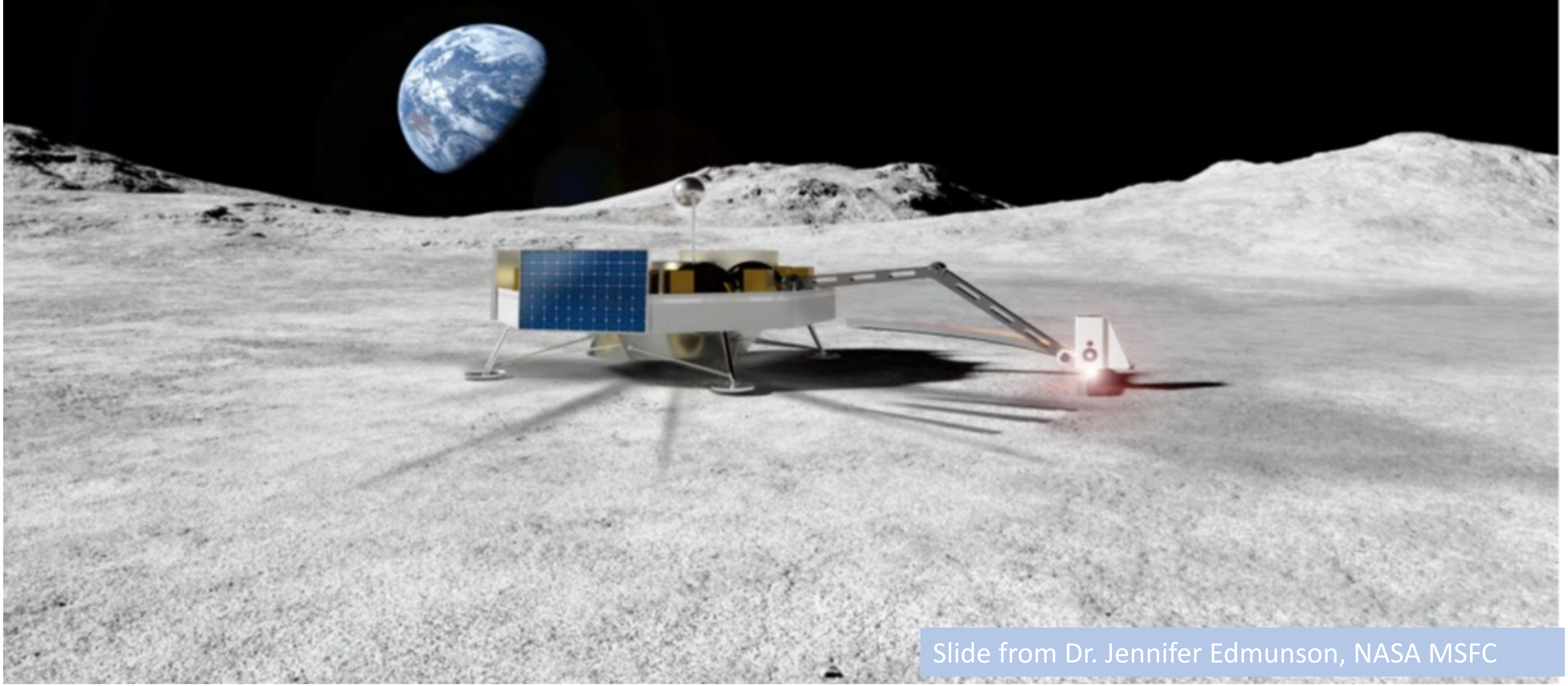
MMPACT Preliminary Concept Demonstration Mission-1

A demonstration mission that serves as a proof of concept for newly developed In situ Resource Utilization (ISRU) additive construction technology.



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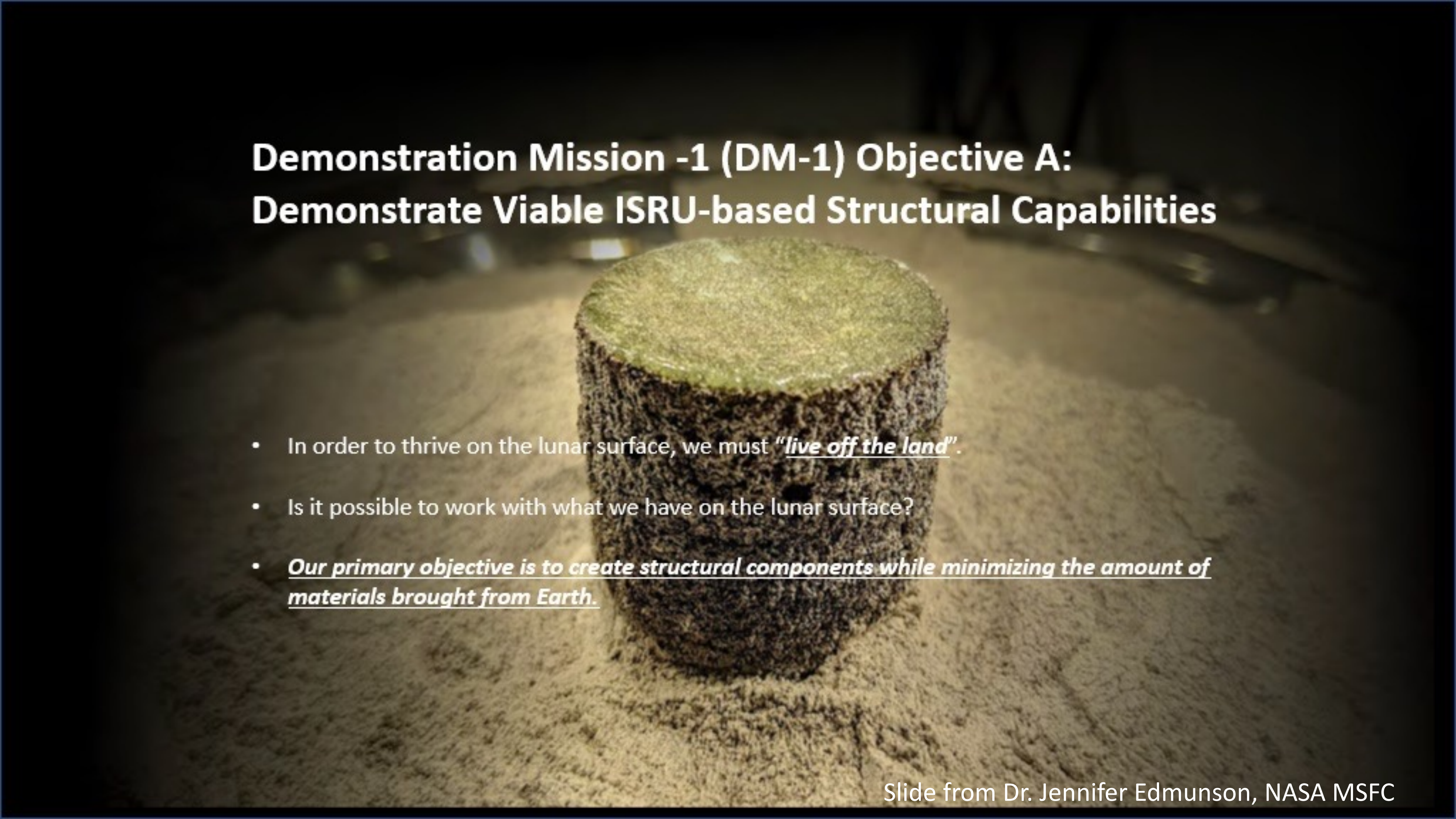


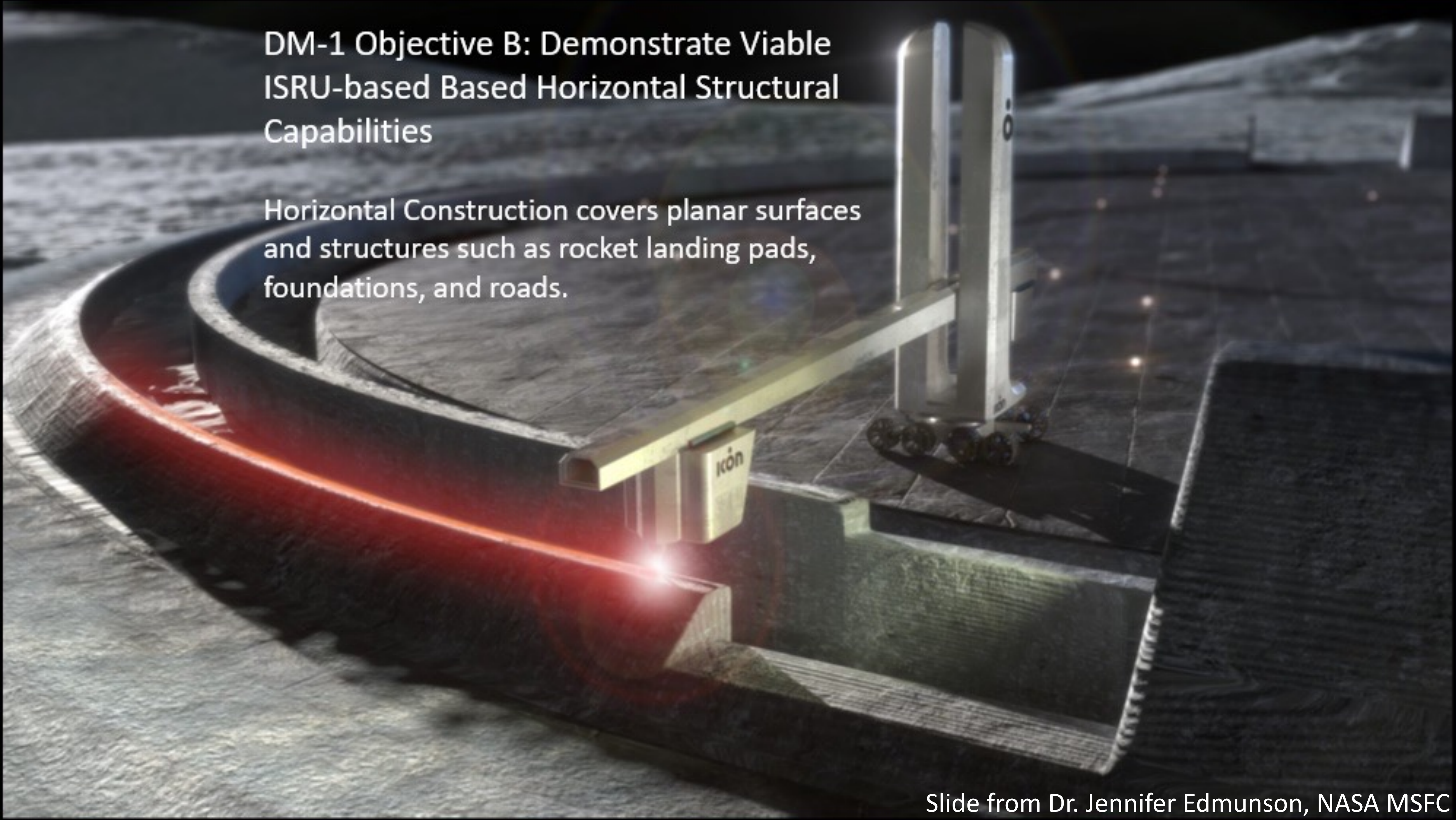
Demonstration Mission -1 (DM-1) Objective A: Demonstrate Viable ISRU-based Structural Capabilities

- In order to thrive on the lunar surface, we must "***live off the land***".
- Is it possible to work with what we have on the lunar surface?
- ***Our primary objective is to create structural components while minimizing the amount of materials brought from Earth.***

Slide from Dr. Jennifer Edmunson, NASA MSFC

DM-1 Objective B: Demonstrate Viable ISRU-based Based Horizontal Structural Capabilities

Horizontal Construction covers planar surfaces and structures such as rocket landing pads, foundations, and roads.



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DM-1 Objective C: Demonstrate Viable ISRU-based Based Vertical Structural Capabilities

Vertical Construction covers volumetric structures such as habitats, garages, and protective berms.

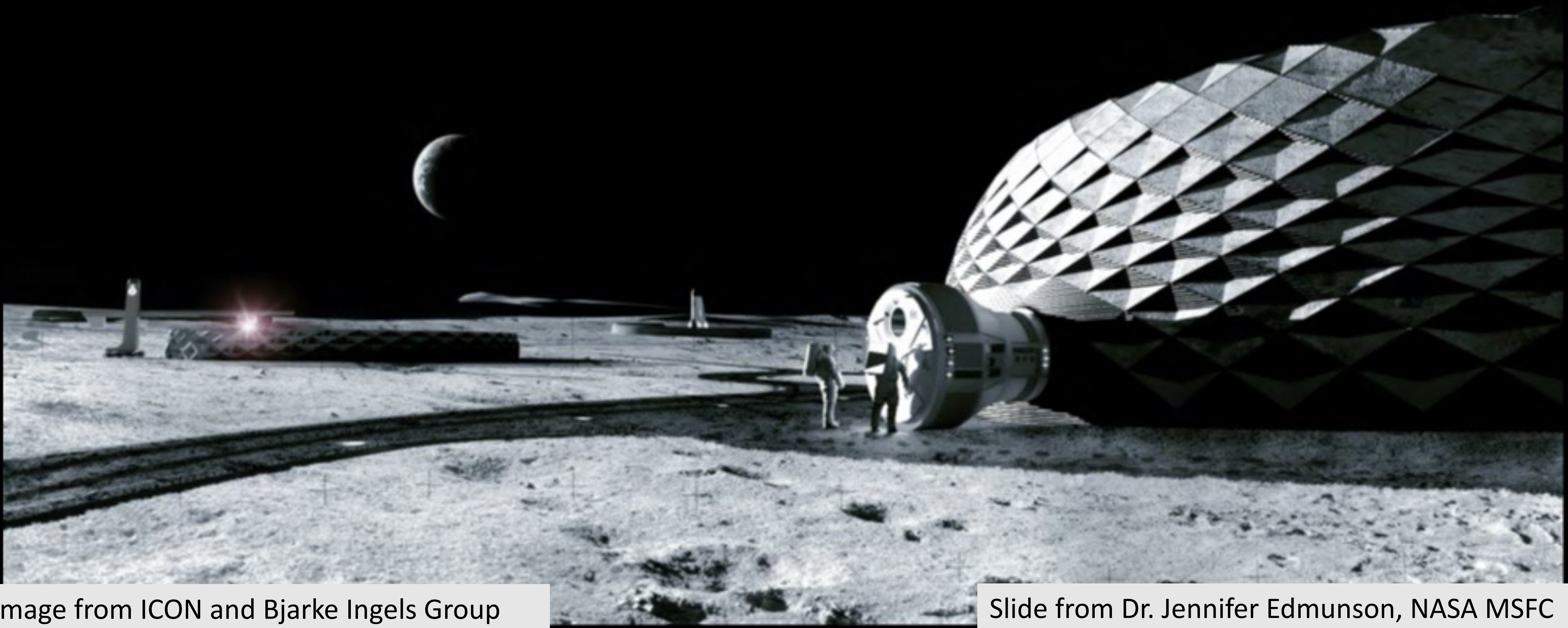

Image from ICON and Bjarke Ingels Group

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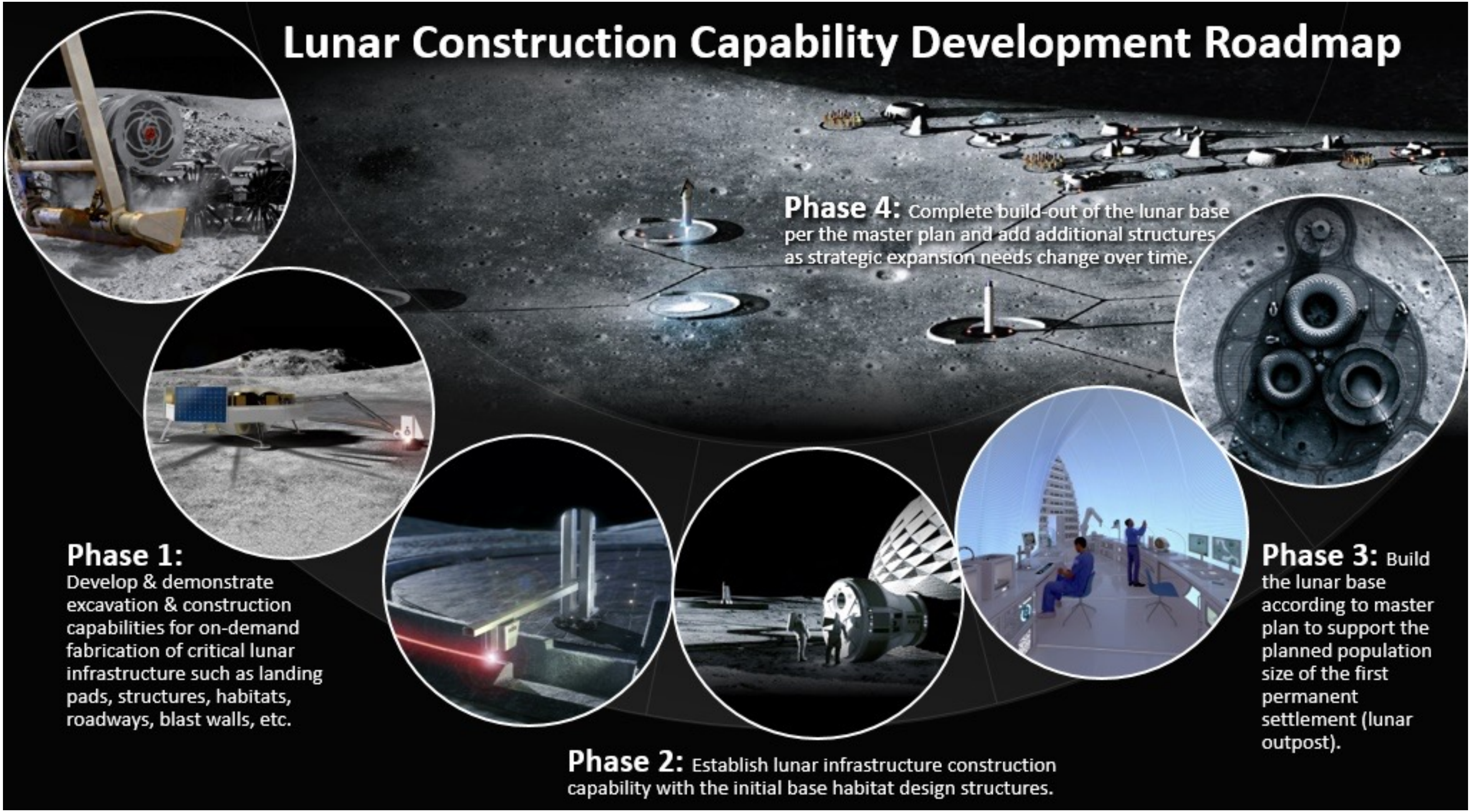
Lunar Construction Capability Development Roadmap
Phase 4: Complete build-out of the lunar base per the master plan and add additional structures as strategic expansion needs change over time.
Phase 1: Develop & demonstrate excavation & construction capabilities for on-demand fabrication of critical lunar infrastructure such as landing pads, structures, habitats, roadways, blast walls, etc.
Phase 3: Build the lunar base according to master plan to support the planned population size of the first permanent settlement (lunar outpost).
Phase 2: Establish lunar infrastructure construction capability with the initial base habitat design structures.